Final Report

Scientific basis for a mushroom food group in the Australian Dietary Guidelines

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Delivery partner:

Australian Mushroom Growers' Association

Project code:

MU22001

Project:

Scientific basis for a mushroom food group in the Australian Dietary Guidelines (MU22001)

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Contents

Public summary

The Australian Dietary Guidelines

The Australian Dietary Guidelines (ADG) are designed to provide up to date advice about the amounts and kinds of foods to eat for health and wellbeing, based on scientific evidence. The current (2013) guidelines are under review and due for update in 2025. Their progress can be followed here.

There are over 2000 varieties of edible mushrooms (Feeney et al 2014). The most frequently consumed mushrooms in Australia are common (*Agaricus bisporus* species) mushrooms, including white button (the most frequently consumed mushroom in Australia and worldwide), swiss brown, cup, flat, and portobello varieties.

In the current ADG, mushrooms are categorised in the 'vegetables and legumes/beans' food group. This food group is divided into five subcategories: 'dark green or cruciferous/brassica', 'orange vegetables', 'root/tubular/bulb', 'legumes/beans' and 'other vegetables'. Mushrooms are placed in the 'other vegetables' subcategory, which includes many of the salad vegetables such as tomato, beetroot, and cucumber.

However, mushrooms are fungi, not vegetables, and have a unique nutritional composition, including being the only natural, non-animal dietary source of vitamin D. In addition, mushrooms lack some of the characterising nutrients of the vegetables core food group, such as vitamin C. Therefore, mushrooms have the potential to make a unique contribution to dietary nutrient intakes.

Project aim and methods

The aim of this project was to establish an evidence-base for repositioning mushrooms within the ADG for the 2025 review. A literature review and dietary modelling provided evidence to advocate for mushrooms to be their own subcategory within a revamped 'vegetable, legumes/beans, and mushrooms' food group.

Key outcomes and benefits

Key outputs from this project include:

1. Delivery of the ***NUTRITIONiQ* Solution – Strategic Plan** (Appendix 1),
2. A **Scientific Summary Report** presenting the scientific evidence and dietary modelling to support the repositioning of mushrooms (Appendix 2),
3. A **Submission Support Report** outlining five recommendations for advocating for the repositioning of mushrooms in the ADG review process (Appendix 3),
4. A **MushroomLink article** communicating the key findings from the Scientific Summary Report (Appendix 4), and
5. An **opinion piece manuscript** submitted for publication in "Advances in Nutrition" (Appendix 5).

There are significant opportunities to be realised from the reclassification of mushrooms within the vegetables core food group. Increased awareness of the nutritional benefits of mushrooms and exposure of mushrooms as their own subcategory, distinct from vegetables, may support increased consumption of mushrooms over time, and provide increased health and nutritional benefits for the Australian population. This change could also be a stepping-stone for the establishment of a new core food group of "mushrooms/fungi" in future ADG updates.

Keywords

Mushrooms; Australian Dietary Guidelines; Vitamin D; Dietary modelling; meat alternative

Introduction

Background

Over the past 10-15 years, there has been a growing scientific evidence base of the health benefits of consuming *A. bisporus*, which is shown in the recent scoping review conducted by Nutrition Research Australia - a key output of MU17002 – Educating Health Professionals about the Nutritional benefit of Mushrooms.

Fungi are neither animal nor plant and grow in a unique way, defined within their own biologically separate kingdom. The most commonly consumed edible fungi, mushrooms, contain a unique package of micronutrients, as well as other bioactive and flavour compounds; a combination of nutrients which are not found in plants or animals alone.

Despite mushrooms being biologically different to plants, they are currently grouped with vegetables in the Australian Dietary Guidelines (ADG), although legumes and nuts (also not vegetables biologically) are itemised separately.

The ADG inform the Australian population on the health and nutrition recommendations for food consumption and are founded on a robust scientific evidence base and review process. With the increasing health professional and consumer focus on dietary patterns according to whether they are derived from 'plants' or 'animals,' fungi foods – a separate kingdom to both plants and animals - appears to have been relatively ignored in the current classification within the ADG.

Project rationale

The ADG are currently in the review process, which offers a rare opportunity to submit the evidence as to why mushrooms should form a food group distinct from vegetables.

Mushrooms offer unique nutritional, health, and culinary properties, which are of benefit to plant-based dietary patterns, however this may fail to be exposed with their classification in the current ADG as a vegetable.

Separating mushrooms from vegetables and establishing a clear serve size recommendation for a healthy dietary pattern with the new ADG will highlight mushrooms for their unique nutritional properties, giving this unique and valuable food source the communication and recognition it deserves.

Methodology

Stage 1

Stage 1 of the project involved determining the best strategic pathways to help achieve repositioning of mushrooms in the updated 2025 ADG. This was completed using Nutrition Research Australia's *NUTRITIONiQ Solution* (Appendix 1). A decision was made to advocate for mushrooms to be its own subcategory within a revamped 'vegetable, legumes/beans, and mushrooms' food group.

Stage 2

Stage 2 involved the collation of relevant evidence to support repositioning of mushrooms in the ADG in the form of a Scientific Summary Report (Appendix 2). This was completed and included dietary modelling to capture the nutritional impact that such a change would have on key population groups in Australia.

Research questions guiding Stage 2 were:

1. What is the biological classification of mushrooms and how does this differ to vegetables?
2. What is the nutritional composition and contribution of mushrooms to the diet and how does this differ to vegetables?
3. What is the significance of mushrooms being a source of vitamin D?
4. What are the key culinary properties of mushrooms and how does these differ from vegetables?
5. What are the unique health effects associated with mushroom consumption and how do these differ from vegetables?
6. What is the effect on nutritional intake if mushrooms were to become their own subcategory within the vegetable food group?

The scientific evidence was collated using two approaches (Figure 1): Questions 1-5: via a scope of the scientific literature, and Question 6 via dietary modelling, based on the approach described for the 2013 Australian Guide to Healthy Eating (Byron et al 2011). Full details, including the search strategy used and description of steps involved in the dietary modelling ae available in Appendix 1 within the Scientific Summary Report (Appendix 2).

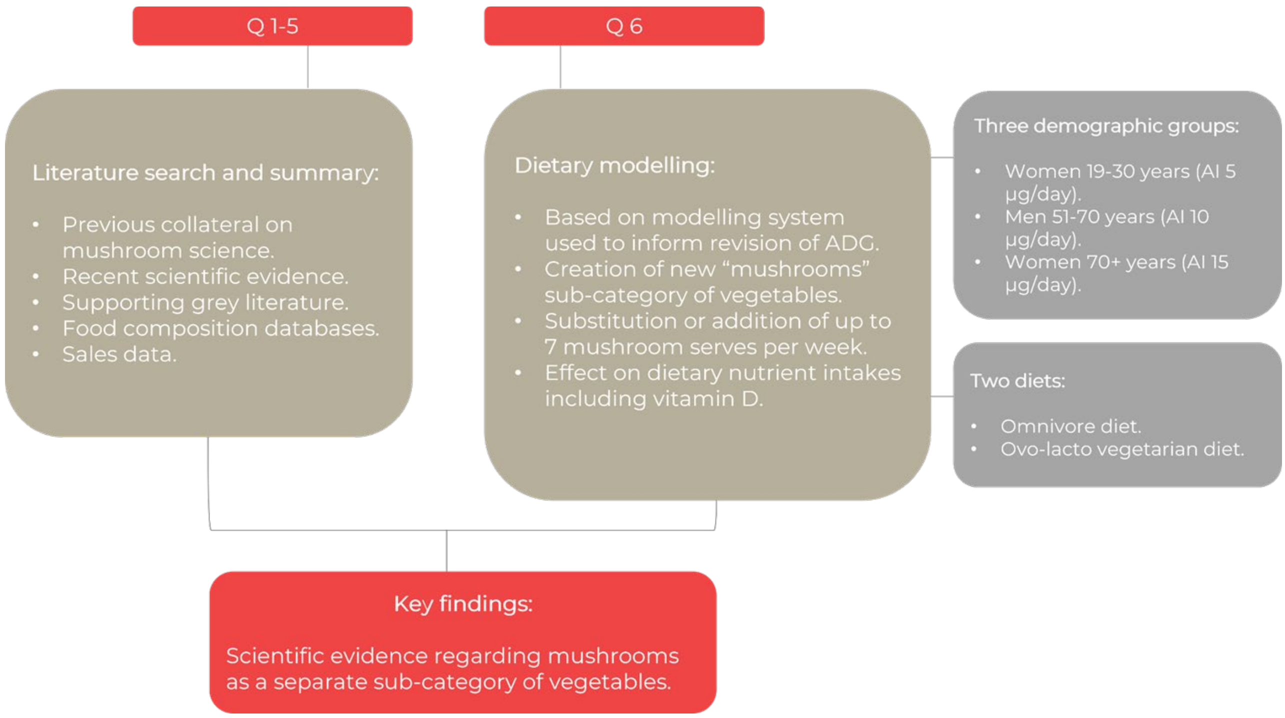

Figure 1. Overview of the methodology used to collate and assess the scientific evidence regarding mushrooms as a sub-category of vegetables. AI, adequate intake.

Stage 3

Translation of this science into key messages that will support the mushroom industry with making a submission to the ADG was the focus of Stage 3. Key advocacy messages based on five key recommendations for the mushroom industry to progress moving forward were presented in the Submission Summary Report (Appendix 3).

During this stage, it was identified that the preparation of a manuscript for publication in a peer-reviewed journal would substantially increase the readership of the project findings, and provide a stronger foundation for the development of advocacy messages. An opinion piece manuscript (Appendix 5) was prepared and submitted to Advances in Nutrition. The manuscript is currently under review.

Results and discussion

In stage 1 of the project, it was identified that the best approach for improving the visibility of mushrooms within the Australian Dietary Guidelines was to advocate for mushrooms to be its own subcategory within a revamped 'vegetable, legumes/beans, and mushrooms' food group. Key evidence collected to support this reclassification included:

- Mushrooms are not vegetables and belong to a distinct biological kingdom, fungi.
- Mushrooms provide a nutrient and bioactive package that is different to vegetables. This includes (but is not limited to) niacin, vitamin B5, biotin, vitamin D, copper, phosphorus, selenium, ergothioneine, beta-glucan, chitin, and phytosterols.
- The vitamin D of mushrooms can be considered as a key distinguishing nutrient that separates it from all other vegetable subcategories.
- Mushrooms are the only non-animal source of dietary vitamin D and can provide more than 100-300% of vitamin D needs upon exposure to UV light.
- There is precedent in dietary guidelines to recognise foods with unique nutrient compositions or different 'distinguishing' nutrients, yet the current ADG do not recognise the unique nutritional composition of mushrooms.
- Australia has high rates of vitamin D deficiency and some of the lowest vitamin D intakes globally. It is the most difficult nutrient to meet population needs for in dietary modelling.
- Unlike vegetables, where taste is a common barrier to consumption, mushrooms have a distinct taste profile that includes an umami flavour and meaty texture and can be a culinary meat substitute without compromising on taste or texture. This can help to improve the intakes of key nutrients, such as fibre and potassium, while also reducing saturated fat and sodium.
- Unlike vegetables, mushrooms improve vitamin D status when exposed to UV-light and may have a specific impact on reducing ovarian cancer risk. This is thought to be due to their distinct bioactive profile.
- If mushrooms were a separate subcategory of vegetables, vitamin D intakes increase. This effect is amplified with UV-exposed mushrooms, where vitamin D needs can be met from as little as 1 serve per week (depending on the age group).
- Mushrooms as a separate subcategory of vegetables can also help adults on a vegetarian diet to meet selenium requirements, with no major adverse effects for nutrient intakes.

The dietary modelling undertaken validated that:

- Current recommended diets in the ADG are deficient in vitamin D and vegetarian diets are deficient in vitamin D and selenium.
- The creation of a new "mushrooms" subcategory of vegetables produced notable increases in vitamin D intakes for adult males and females.
- This effect is amplified with UV-exposed mushrooms, where vitamin D needs were met with as little as 1 x 75 gram serve per week for women aged 19-30 years.
- One 75 g serve of mushrooms per day also enabled some ovo-lacto vegetarian adults to meet their selenium requirements.

The second stage of the project involved the translation of the key evidence collected into key advocacy messages for the mushroom industry and AMGA. Five recommendations were put forward for the revision of the ADG:

Address low vitamin D intakes

1. Change the wording of the current "Vegetables and legumes/beans" food group to, "Vegetables, mushrooms, and legumes/beans."
2. "Mushrooms" to be an additional subcategory within the "Vegetables, mushrooms, and legumes/beans" food group.
3. Provide specific practical recommendations for enhancing the vitamin D content of mushrooms: buying vitamin D enriched mushrooms and/or putting mushrooms in sunlight (for 15 to 60 minutes).

Provide greater practical advice to lower sodium intake

4. Provide specific practical recommendations for using foods high in umami and low in sodium, such as mushrooms, as a strategy for reducing sodium intake.

Provide greater practical advice to help relevant population groups to lower red meat intake without increasing ultra-processed or discretionary food consumption.

5. Provide specific practical recommendations to reduce red meat intake using mushrooms as a culinary substitute, for relevant demographic groups.

The ADG aim to support health and provide Australians with a sufficient intake of all nutrients within a diet. This is achieved by grouping foods based on similar nutritional compositions. However, the current ADG do not meet vitamin D needs and do not acknowledge the distinct nutritional composition of mushrooms.

Findings from a scope of the scientific and supporting literature were combined with dietary modelling. Mushrooms have a unique nutritional composition, including being a source of vitamin D, which is explained by their unique biology. When exposed to UV-light, vitamin D content increases substantially, and mushrooms have shown the ability to make a significant impact on vitamin D status. Dietary modelling confirmed that categorising mushrooms as its own subcategory of foods within the 'Vegetables and legumes/beans' food group may have a notable impact on vitamin D intakes. Their culinary properties are also diverse to vegetables, and they can help to reduce sodium and saturated fat intake and increase fibre and potassium intake via meat replacement in meals.

Together, the totality of the evidence shows that revamping the position of mushrooms within the ADG has a beneficial effect on modelled micronutrient intakes in the Australian population and the potential to make a significant contribution to solving current public health problems.

Overall, the project has delivered a firm foundation for the mushroom industry to advocate for a reclassification of mushrooms within the ADG as its own sub-category within the vegetable food group. The evidence collated, and dietary modelling undertaken, has provided a clear, strategic direction for the industry and AMGA to advocate for change.

Outputs

Table 1. Output summary

Output	Description	Detail
Project Logic	The project logic is a model illustrating how project outcomes will be achieved, including the inputs and activities required to achieve these outcomes. Other components include project outputs (tangible deliverables) and the project's contribution to the relevant SIP.	Delivered in Milestone 102
M&E Plan	Outlines the project's monitoring and evaluation plan, including evaluation questions, outputs, and outcomes.	Delivered in Milestone 102
Risk Register	Plan outlining identified project risks and mitigation strategies.	Delivered in Milestone 102
Stakeholder Engagement Plan	Plan outlining key stakeholders for the project, and the required levels of engagement.	Delivered in Milestone 102
Project Strategic Plan	Nutrition Research Australia used their *NUTRITIONiQ Solution* to develop a Strategic Plan for the project. It is a 4-step process involving key project stakeholders to determine the best approach for achieving project outcomes.	The final Strategic Plan was prepared in March 2023 and presented to the project team and Hort Innovation. Appendix 1: NUTRITIONiQ Mushrooms in the ADG
MushroomLink article	MushroomLink is the Australian mushroom industry's communications program aimed at providing the latest research, development, and marketing news from here and internationally.	Delivered in Milestone 103 Appendix 4: Mushrooms in the Australian Dietary Guidelines
Scientific Evidence Report - Literature scoping and dietary modeling	Comprehensive scope of the scientific literature summarising evidence-based points for the differentiation of mushrooms as a separate sub-category within the vegetable's food group. Mathematical modelling to determine the nutritional impact of recommending that one serve of the vegetables food group (per day) should be mushrooms, with a spotlight on vitamin D.	Delivered in Milestone 103 Appendix 2: Scientific Evidence Report, including literature scoping and dietary modeling
Submission Support Report	A report providing the key messages and substantiation to support a submission to the draft ADG that seeks to influence inclusion of specific communication around the unique and valuable dietary contribution of mushrooms. The ultimate, longer-term objective is that the fungi/mushrooms food kingdom is recognised as a separate core food group within the ADG.	Delivered in Milestone 103 Appendix 3: Mushrooms in the Australian Dietary Guidelines: Submission Support Report
Publication	Expert narrative review summarising the evidence-based rationale surrounding mushrooms and their inappropriate	Appendix 5: Manuscript title: A food-based solution to vitamin D deficiency? Perspective on the

Output	Description	Detail
	placement within the Dietary Guidelines	untapped role of mushrooms Journal: Advances in Nutrition Submission date: 28 September 2023
Final Project Report	The Final Report outlines the key findings from the project and achievement of the outcomes as specified in the M&E Plan.	This Report (Milestone 190)

Outcomes

Table 2. Outcome summary

Outcome	Alignment to fund outcome, strategy and KPI	Description	Evidence
Intermediate outcomes			
Strategic approach to project finalised	Mushroom SIP 2022 - 2026 Outcome 1 Strategy 1: Increase domestic demand for Australian mushrooms through improving knowledge, attitudes, and purchase intent. KPI: Use of nutritional information to support consumer demand	International dietary guidelines and trends were examined (e.g., mushrooms classified as a vegetable globally). Consumer consumption patterns and trends were examined (e.g., mushrooms increasingly normalised as a meat alternative). Key industry stakeholders consulted. Different strategic options developed and evaluated. Regular project meetings were also held with AMGA and Hort Innovation at key decision-points.	Appendix 1: NUTRITIONiQ Mushrooms in the ADG
Scientific evidence collated to support changes to the Australian Dietary Guidelines to differentiate mushrooms	Mushroom SIP 2022 - 2026 Outcome 1 Strategy 1: Increase domestic demand for Australian mushrooms through improving knowledge, attitudes, and purchase intent. KPI: Use of nutritional information to support consumer demand	Project findings, including literature review and dietary modeling have established an evidence-based argument for mushrooms to be their own subcategory within the vegetables core food group – "vegetables, mushrooms, and legumes/beans".	Appendix 2: Scientific Evidence Report Appendix 3: Submission Support Report
Submission Report delivered to NHMRC Australian Dietary Guidelines (ADG) Review	Mushroom SIP 2022 - 2026 Outcome 1 Strategy 1: Increase domestic demand for	Based on key findings, key messages have been developed that recommend that future advocacy and	Appendix 3: Submission Support Report will support the AMGA to

Outcome	Alignment to fund outcome, strategy and KPI	Description	Evidence
Committee	Australian mushrooms through improving knowledge, attitudes, and purchase intent. KPI: Use of nutritional information to support consumer demand	submission to the NHMRC ADG Review focus on advocating for mushrooms to be a sub-category within the vegetables core food group. Submission will need to occur after project end, within the current NHMRC timelines for the ADG review. The NHMRC do not accept public submissions outside of their timelines.	advocate for reclassification of mushrooms with ADG
End-of-project outcomes			
NHMRC are well informed of the unique properties and science supporting health benefits of mushrooms in the human diet	Mushroom SIP 2022 - 2026 Outcome 1 Strategy 1: Increase domestic demand for Australian mushrooms through improving knowledge, attitudes, and purchase intent. KPI: Use of nutritional information to support consumer demand	Advocacy will need to occur after project end, within the current NHMRC timelines for the ADG review. The NHMRC do not accept public submissions outside of their timelines. The submission support report will support with this advocacy process and ensure that the industry is best prepared.	Appendix 3: Submission Support Report Appendix 5: Manuscript: A food-based solution to vitamin D deficiency? Perspective on the untapped role of mushrooms
An evidence-base exists to substantiate a request to differentiate mushrooms in the Australian Dietary Guidelines.	Mushroom SIP 2022 - 2026 Outcome 1 Strategy 1: Increase domestic demand for Australian mushrooms through improving knowledge, attitudes, and purchase intent. KPI: Use of nutritional information to support consumer demand	Project findings have established an evidence-based argument for mushrooms to be their own subcategory within the vegetables core food group: • Mushrooms provide a nutrient and bioactive package that is largely different to the vegetables core food group. • The naturally occurring vitamin D content of mushrooms can be considered as a key distinguishing nutrient that separates it from all other vegetable subcategories in the dietary guidelines. • If mushrooms are modelled as a separate subcategory of	Appendix 2: Scientific Evidence Report Appendix 3: Submission Support Report Appendix 5: Manuscript: A food-based solution to vitamin D deficiency? Perspective on the untapped role of mushrooms

Outcome	Alignment to fund outcome, strategy and KPI	Description	Evidence
		vegetables, vitamin D intakes increase substantially. This effect is amplified with UV-exposed mushrooms, where vitamin D needs can be met from as little as 1 to 4 75 g serves per week.	

Monitoring and evaluation

Table 3. Key Evaluation Questions

Key Evaluation Question	Project performance	Continuous improvement opportunities
To what extent has the project established a case for mushrooms to be differentiated from other vegetables in the ADG?	Project findings have established an evidence-based argument for mushrooms to be its own subcategory within the vegetable food group – *vegetable, legumes/beans, and mushrooms*. The argument is based on three key areas: the ability for mushrooms to address low vitamin D intakes, to support practical advice for lowering sodium intakes, and assisting relevant population groups to lower their red meat intake without increasing ultra-processed or discretionary food consumption.	Success in establishing mushrooms as a subcategory within the vegetable food group in the 2025 ADG review could be leveraged to then advocate for mushroom to be recognised as their own, unique food group (mushrooms/fungi) in future ADG reviews.
To what extent has the Submission Report met the NHMRC ADG Review guidelines?	The recommendations provided in the Submission Support Report were developed based on a solid understanding of the nutrition landscape, including the nutrition profile of mushrooms, Australian and international dietary guideline trends and precedents, lack of an established mushroom serving size, trends in red meat alternatives, and vitamin D deficiencies in the current ADG. Four potential pathways were identified for the ADG review: 1. New fungi food group 2. Sub-category within vegetables 3. Meat alternative 4. Solution to the vitamin D problem. Based on the key findings, it was recommended that option 2 would have the most success under the current ADG review.	The NHMRC will undertake public consultation throughout the dietary guidelines review process. AMGA should be active participants in this process to provide scientific articles and feedback, which will be considered before the updated guidelines are finalised.
To what extent were consumer, key opinion leaders and industry's perspectives included in the project?	Expert consultation was undertaken with Glenn Cardwell and Greg Seymour to inform the *NUTRITIONiQ* process. International dietary guidelines and trends were examined (e.g.,	

Key Evaluation Question	Project performance	Continuous improvement opportunities
	mushrooms still classed as vegetable globally). Consumer consumption patterns and trends were examined (e.g., mushrooms increasingly normalised as a meat alternative). Regular project meetings were also held with AMGA and Hort Innovation at key decision-points. Evidence of the above is available in Appendix 1.	
To what extent have project findings been disseminated through other relevant communication projects?	The project findings were disseminated via a MushroomLink article [Mushrooms in the Australian Dietary Guidelines] and submitted to a peer-reviewed scientific journal [Advances in Nutrition].	Multiple opportunities exist for the AMGA to advocate for a change to the ADG and communicate findings from the dietary modelling to establish recommended serve sizes for mushrooms.
Did the project team engage all relevant stakeholders (key opinion leaders, consumers, and industry) in the workshop/s?	As above – Expert consultation	

Recommendations

Recommendations for future advocacy by AMGA

Five recommendations have been put forward for the revision of the Australian Dietary Guidelines:

Address low vitamin D intakes

1. Change the wording of the current "Vegetables and legumes/beans" food group to, "Vegetables, mushrooms, and legumes/beans".
2. "Mushrooms" to be an additional subcategory within the new "Vegetables, mushrooms, and legumes/beans" food group.
3. Provide specific practical recommendations for enhancing the vitamin D content of mushrooms: buying vitamin D enriched mushrooms and/or putting mushrooms in sunlight (for 15 to 60 minutes).

Provide greater practical advice to lower sodium intake.

4. Provide specific practical recommendations for using foods high in umami and low in sodium, such as mushrooms, as a strategy for reducing sodium intake.

Provide greater practical advice to help relevant population groups to lower red meat intake without increasing ultra-processed or discretionary food consumption.

5. Provide specific practical recommendations to reduce red meat intake using mushrooms as a substitute, for relevant demographic groups.

Recommendations for future R&D projects

Recommendation: Economic modelling to determine the potential of UV-mushrooms to reduce healthcare costs.

Background:

- Vitamin D deficiency is a significant public health problem that leads to higher health care costs for the government.
- UV-mushrooms produce large amounts of vitamin D and their effect on vitamin D status can be equivalent to a vitamin D supplement.
- Cost is a barrier for the industry to employ UV-mushrooms as standard practice, yet such a change would help to address vitamin D deficiency and reduce health care costs for the government.

Approach:

- **Step 1 (Stop/Go step):** Education and consultation with the industry & growers. Understand their appetite for change and the costs and feasibility of UV-mushrooms as standard practice.
- **Step 2:** Economic modelling to quantify the healthcare cost savings of UV-mushrooms. Consider a feasibility assessment with modelling done at different levels of feasibility.
- **Step 3:** Publish white paper report and scientific manuscript.
- **Step 4:** Advocate for government funding to support the industry with employing UV-mushrooms as standard practice.

Benefit: Mushrooms become an evidence-based, government supported, industry-led solution to vitamin D deficiency = positive PR, improved health credentials, and increased demand for mushrooms.

Refereed scientific publications

Journal article – under review “Advances in Nutrition”

Title: A food-based solution to vitamin D deficiency? Perspective on the untapped role of mushrooms

Authors:

- Carlene Starck, PhD
- Tim Cassettari, BSc, BAppSc, APD
- Jutta Wright, BAppSci, MNutDiet (APD), GDipHerbMed
- Flavia Fayet-Moore, PhD, APD, RNutr, FASLM

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Feeney, M.J., A.M. Miller, and P. Roupas, *Mushrooms-Biologically Distinct and Nutritionally Unique: Exploring a "Third Food Kingdom".* Nutr Today, 2014. **49**(6): p. 301-307.

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A. and Jonell, M., 2019. *Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems*. The lancet, 393(10170), pp.447-492.

Intellectual property

No project IP or commercialisation to report.

Acknowledgements

The project team would like to acknowledge the expert advice provided by:

- Glenn Cardwell
- Greg Seymour

Appendices

Appendix 1 - NUTRITIONiQ Mushrooms in the ADG

Appendix 2 - Scientific Evidence Report

Appendix 3 - Submission Support Report

Appendix 4 - MushroomLink article (Mushrooms in the Australian Dietary Guidelines)

Appendix 5 – Manuscript (A food-based solution to vitamin D deficiency? Perspective on the untapped role of mushrooms)

NUTRITIONiQ™

Mushrooms in the ADG

March 2023

NRAUS

4 Steps to Solutions

1 **Business needs**

Understanding the business objectives including its short, medium and long term goals

2 **Nutrition Landscape**

Mapping out the current landscape in relation to the problem or issue to be solved and collating supporting evidence to inform decision making and strategy

NUTRITIONiQ™

3 **Pathways to success**

Working together to navigate the nutrition landscape and identify gaps and opportunities to fulfill

4 **Strategic solutions**

Providing recommendations on the best approach for return on investment that maximises the existing opportunities

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Business needs

STEP 1

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How do we develop the rationale and substantiation for mushrooms to be specifically recommended in the ADG?

(ultimately, as its own food group)

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What does success look like?

Ultimate media headlines for Mushrooms and ADG

- "World first recommendation on why all Australians should eat more mushrooms"
- "New food group defined in ADG"
- "Mushrooms unique to health"
- "More to mushrooms than just vegetables"
- "3 Mushrooms every day keeps the Dr away"
- "ADG announces new food kingdom"

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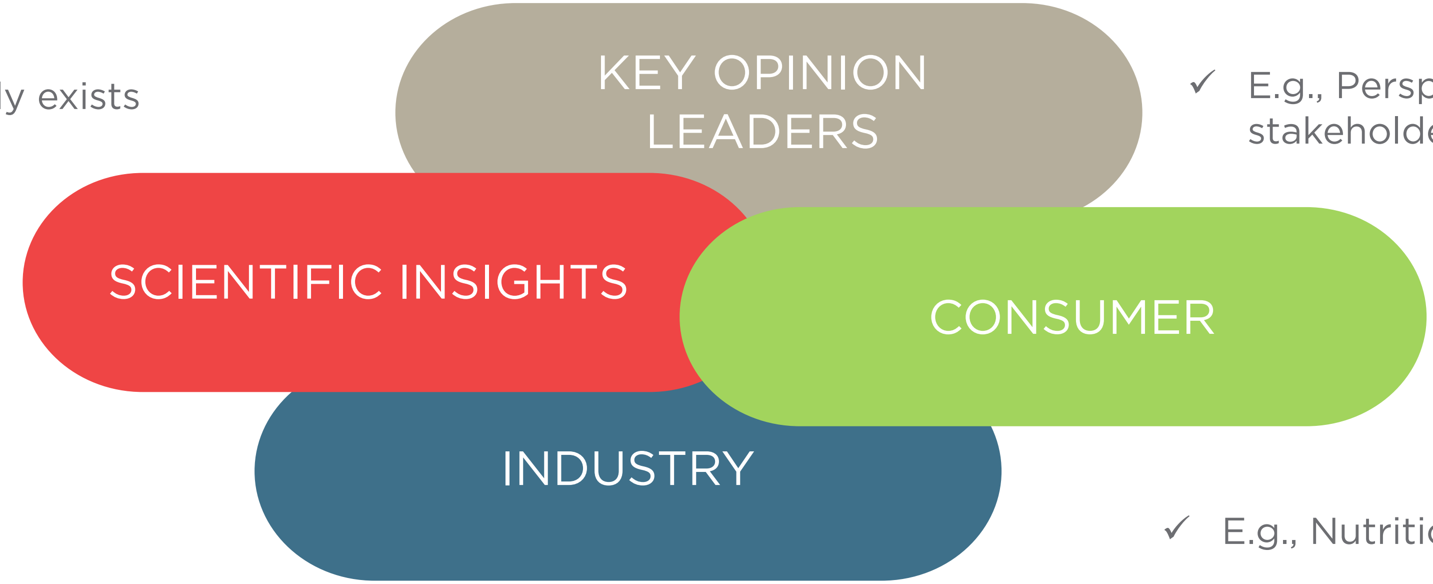
Nutrition Landscape

- ✓ E.g., What science currently exists
- ✓ E.g., Identify strengths, limitations and gaps in the literature
- ✓ E.g., Industry products



- ✓ E.g., Perspectives of key stakeholders
- ✓ E.g., Nutrition trends

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Landscaping Questions

Landscaping Area	Key Questions to answer in the landscaping
Industry	Do mushrooms have enough nutrients to be classified as their own food group? How have other food groups been established? What have nuts and legumes done?
	What are other dietary guidelines saying (globally) around mushrooms/fungi? Are there any other guidelines focused on mushrooms currently in development? Or that already separate out mushrooms as a food group or have specific recommendations around mushrooms?
	What are the Dietary Guideline trends? Are we moving away from food groups? What are other non-food group options for separating out mushrooms/fungi?
Consumer	What are some consumer campaigns around mushrooms being unique in AUS or globally?
	How do consumers view food? Are they approaching seeking health or to prevent illness?
	What are the perceptions around mushrooms being vegetables vs fungi? How might these perceptions impact behaviour change? What are the potential barriers to changing perception and behaviour? Are there any strategies that might be useful in creating this change in perception?
Science	What are the unique nutritional properties of mushrooms or fungi compared to other vegetables?
	What are the other (edible/dietary) fungi foods other than mushrooms?
	What is the economic impact of separating out mushrooms?
	What is the nutritional impact of separating out mushrooms? Does this change if mushrooms are an addition or a replacement? How does the nutritional composition of mushrooms affect the diet when placed as a separate food group?
Key opinion leader (KOL)	What are key stakeholder opinions on a different food group, and the whole “food group” concept?
	What is the sustainability story of mushrooms? What is the current communication around this story?

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Nutrition Landscape Findings

STEP 2

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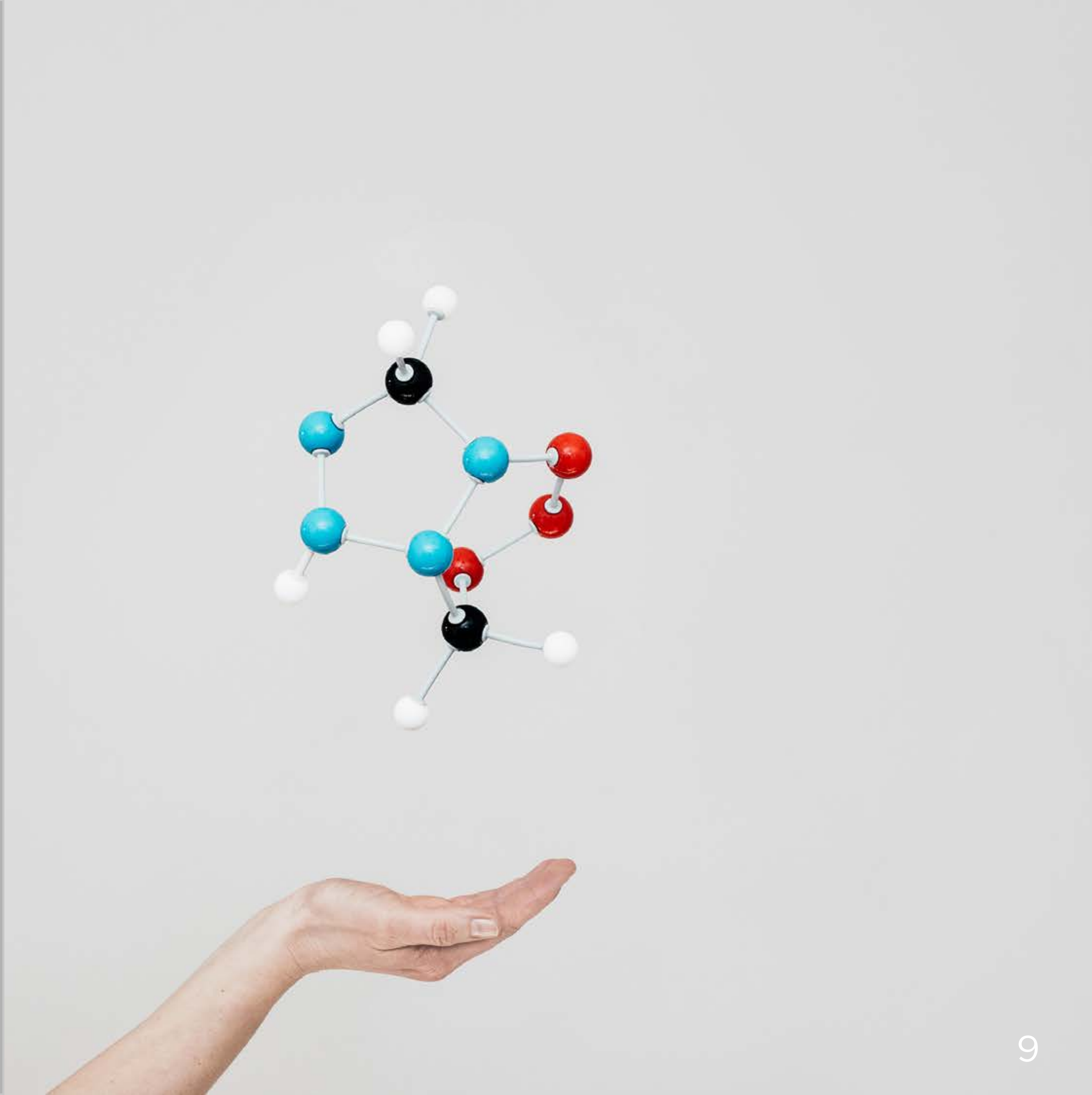
SCIENTIFIC INSIGHTS



Nutrient rich

Per 100 g (content claims):

- Good source **biotin** (81-102% ESADDI)
- Source of **copper** (11% ESADDI)
- Good source of **niacin** (61-67% RDI)
- Good source **B5** (27 - 35% ESADDI)
- Source **phosphorus** (10-11% RDI)
- Contains **potassium** (> 200 mg/100 g serve)
- Good source **riboflavin** (29 - 33% RDI)
- Good source **selenium** (33-36% RDI)
- Source of **vitamin D*** (up to 28% RDI)
- Source of **folate*** (11% RDI)

Plant and Food Research NZ (A. bisporus)
****Australian Food Composition Database (AFCD)***

Impact dietary intake

When mushrooms (84 g of white + crimini + portabella at 1:1:1 ratio) were added to a healthy diet (USDA Food Patterns)**, there was a:

- 2–3% increase in **fibre**
- 8–12% increase in **potassium**
- 12–18% increase in **riboflavin**
- 11–26% increase in **niacin**
- 11–23% increase in **selenium**
- 16–26% increase in **copper**

*****Agarwal and Fulgoni 2021***

Mushrooms are a source of key nutrients in the diet, including vitamin D.

Reservoir of vitamin D

- Mushrooms exposed to UV light become Vitamin D-enriched, due to the enzymatic conversion of ergosterol to D2; this increases vitamin D content to an average of **22 µg (220% RDI) per 100 g serve** (Cardwell 2018; AFCD)
- Modelling** found that the dietary addition of UV-exposed mushrooms **increased dietary vitamin D** content by 67–90%.

Unique benefits of speciality mushrooms

- Some **speciality mushrooms** have increased nutrient levels (including vitamin D) compared to more common mushrooms (button, cremini, portabella).
- Modelling** found that the dietary addition of **oyster mushroom** increased vitamin D by 8-11% and choline by 10–16%.

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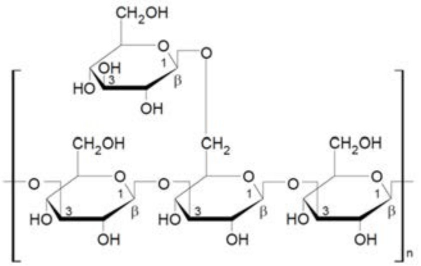
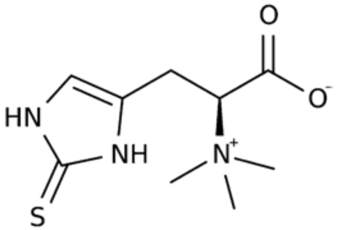
Mushrooms contain a unique cohort of bioactives



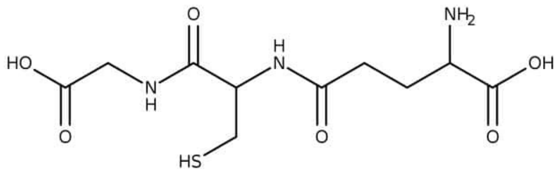
Beta-glucan

- Structurally and functionally distinct from cereal beta-glucans.
- Immunomodulatory and anti-inflammatory effects in pre-clinical studies, as well as adjuvant for cancer treatment.
- Effect on cardiometabolic health (as for cereal beta-glucans) yet to be established.



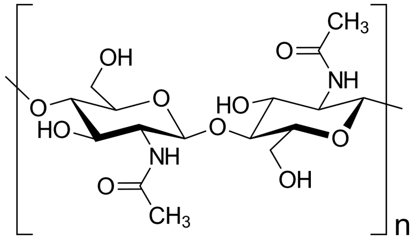
Ergothioneine

- Potent antioxidant amino acid, linked to benefits for cardiovascular health and reduced risk of mortality.
- Highest dietary source; others are kidney beans and liver.
- Speciality mushrooms often have highest levels.
- More concentrated in cap vs stem and in later cropping flushes.



Glutathione

- Potent antioxidant, roles in detoxification and inflammation.
- Speciality mushrooms often have highest levels.
- More concentrated in cap vs stem and in later cropping flushes.
- Other dietary sources are fruits and veggies, and fresh meat.



Chitin

- Prebiotic; source of insoluble fibre.
- Have also shown benefits for immune health, CVD, metabolic health, and wound healing.
- Other dietary sources are shellfish and insects.

As well as.. Polyphenols, serotonin, lectins, short chain fatty acids, lovastatin (reduces cholesterol), and anti-inflammatory polysaccharides (such as mannogalactan).

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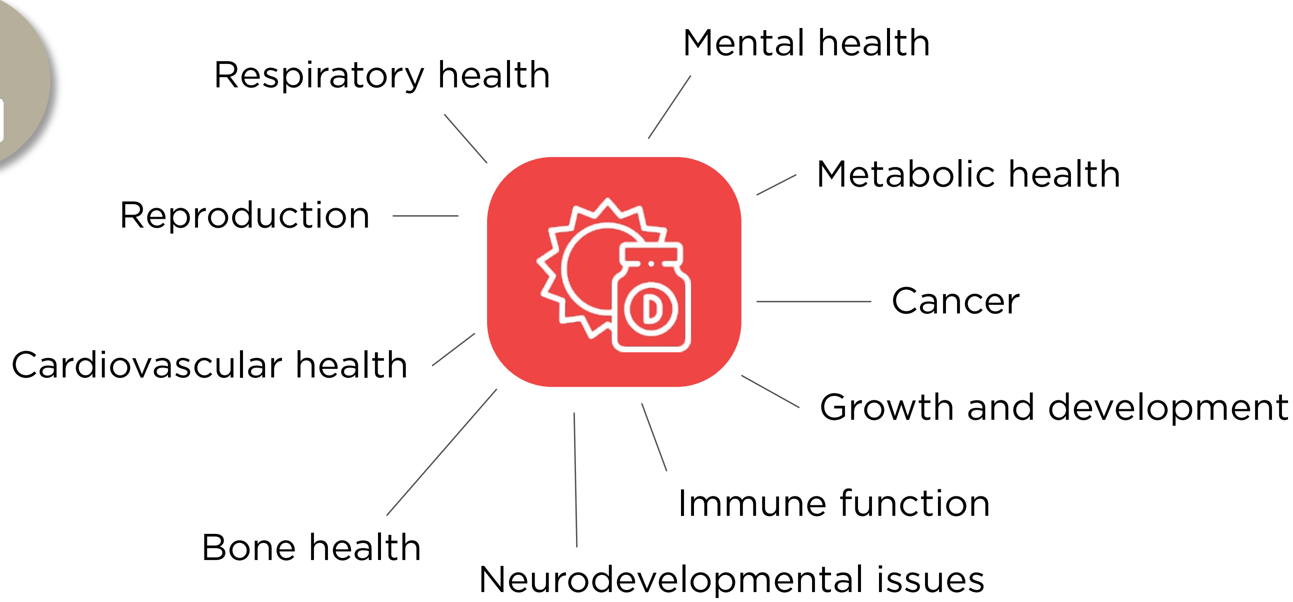
Usman 2021; Cerletti 2021; Kalaras 2017; Dubost 2007; Ba 2021; Dong 2019.

Mushrooms have been linked to health benefits & vitamin D-enriched mushrooms have the potential to significantly impact human health.

Health benefits associated with mushroom consumption in humans include:

- **Lower risk of cancer** (*Ba 2021; SLR and MA*)
- **Lower risk of all-cause mortality** (*Ba 2021; cohort*)
- **Improved markers of metabolic health, mucosal immune function, gastrointestinal health** (including microbiome), cancer, and vitamin D status (*Blumfield 2020; scoping review*)
- **Reduced bodyweight** (by 7 pounds), BMI (by 1.53 units), and waist circumference (by 2.6 inches), as well as improved blood pressure, blood lipids, and inflammatory markers with use in place of meat 3 meals/week for one year (*Podder 2013; RCT*)
- **Reduced hunger** and increased fullness (although increased adverse GI symptoms) with use in place of meat twice daily for 10 days (*Hess 2018; RCT, PhD thesis*)
- **Reduced salt intake:** Consumers preferred a 45% mushroom with reduced sodium taco filling compared to its full sodium counterpart (*Wong 2017 & 2019*)

A large range of health benefits have been associated with optimal vitamin D status or intake of at least 400 IU/day (10 μg/day) in SLRs and MAs:



Vitamin D supplementation is often required to maintain optimal vitamin D status, as sunlight exposure and dietary intake alone is usually insufficient. ~ *Amrein 2020*

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Mushrooms are biologically & nutritionally distinct from vegetables

Mushrooms are fungi, not plants

- Decomposers, obtaining energy from the death of plants and animals
- Plants are producers, producing their own energy from sunlight via photosynthesis

A distinct set of key nutrients & bioactives

- Mushrooms provide unique nutrients but lack many of the defining nutrients of vegetables.
- Mushrooms contain a unique cohort of bioactives but lack the distinguishing bioactives of vegetables (carotenoids)
- Essential amino acid composition of many mushrooms is complete vs incomplete AA composition of vegetables.

Mushrooms uniquely provide vitamin D

- Mushrooms are the only non-animal source of dietary vitamin D.
- When exposed to sunlight, mushrooms can also produce high levels of additional vitamin D (well over the RDI).

Food group	Mushrooms (100 g serve)	Vegetables
Key distinguishing nutrients*		Carotenoids Vitamin C **Folate** Fibre **Potassium** Carbohydrate
Other significant nutrients**		Magnesium Iron
Additional nutrients (FCDB)	**Copper** **Phosphorus** **Potassium** **Selenium** **Vitamin B2** **Vitamin B3** **Vitamin B5** **Biotin** **Folate** **Vitamin D**	
Additional bioactives	Beta-glucan Ergothioneine **Glutathione** Chitin Polyphenols	Polyphenols **Glutathione**

** Modelling to inform the Australian Guide to Healthy Eating*
*** From Eat for Health, Educators Guide*

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The nutritional characteristics of mushrooms differ from other food groups

Food group	Mushrooms (100 g serve)	Vegetables	Fruit	Grains	Milk and alternatives	Meat & alternatives		
						Meats	Legumes	Nuts and seeds
Key distinguishing nutrients*		Carotenoids (vitamin A) Vitamin C **Folate** Fibre **Potassium** Carbohydrate	Vitamin C Fibre **Folate** Vitamin B6	Iron Fibre Vitamin B1 **Folate** Magnesium **Vitamin B3**	Calcium **Vitamin B2** Vitamin B12 Zinc **Potassium** Vitamin A	Iron Zinc Vitamin B12 (animal) Omega-3		Magnesium **Potassium** Omega-6 Vitamin E
Other significant nutrients**		Magnesium Iron	Carbohydrate Beta-carotene **Potassium**	Protein Energy Carbohydrate Zinc **Vitamin B2** Vitamin E Iodine	Energy Fat Carbohydrate Magnesium Protein	Protein Energy Fibre (plant) **Vitamin B3**		
Additional nutrients (FCDB)	**Copper** **Phosphorus** **Potassium** **Selenium** **Vitamin B2** **Vitamin B3** **Vitamin B5** **Biotin** **Folate** **Vitamin D**			**Potassium** Manganese	**Folate** **Biotin** **Vitamin B3** **Vitamin A** **Phosphorus** **Iodine**	Iodine **Potassium** **Phosphorus** **Selenium** **Vitamin B2** **Vitamin B5** Vitamin B6 **Folate** **Vitamin D**	Calcium Magnesium Manganese Molybdenum **Phosphorus** **Potassium** Vitamin B1 **Folate** Vitamin C	Vitamin E **Folate** **Biotin** **Vitamin B5** Vitamin B1 **Potassium** **Phosphorus** **Copper** Manganese

** Modelling to inform the Australian Guide to Healthy Eating; ** From Eat for Health, Educators Guide*

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Mushrooms are more sustainable than other food groups and just as nutritious, but not more affordable.

CHARACTERISTIC	MEASUREMENT TOOL	FOOD GROUP						
		Mushrooms	Vegetables	Fruit	Grains	Milk and alternatives	Meat & alternatives	
NUTRITIOUS • Ability to supply key nutrients	Nutrient density index per 100 kcal	**103 – 109**	97 - 479	56 - 282	13 - 23	12 - 58	5 - 60	=
AFFORDABLE • Cost of nutrition provided	Nutrient density to cost ratio	**14 - 19**	166 – 492	12 - 92	291 - 348	24 - 210	50 - 231	↓
SUSTAINABLE • Impact on the environment	Carbon footprint (kg CO_2 per pound consumed)*	**0.5 (0.08 kg/serving)**	Broccoli 0.9	NR	NR	**Cheese 6.1**	**Chicken, 3.1 Pork, 5.5 Salmon, 5.4 Eggs, 2.2 Tofu, 0.9**	↑ ↑
	Litres of water required** (per 1 kg produced)	**20**	**Potatoes, 280**	**Apples, 800**	**Wheat, 500 Rice, 2,500**	**NR**	NR	

+ Additional **environmental** benefits of mushrooms**

- **Minimal land space** + high yield (vertical growing method); a 15 ha site yields 38 ha of cropping area – produces nearly 10,000 tonnes of mushrooms/year.
- **Circular farming:** 100% of the used compost is recycled (in NZ); given to farmers etc use as fertilizer.
- **Spent compost helps improve** soil structure, water properties and microbiota, and provides valuable nutrients including P. K, and N.

** American Mushroom Organisation; ** Kiwi Mushrooms*

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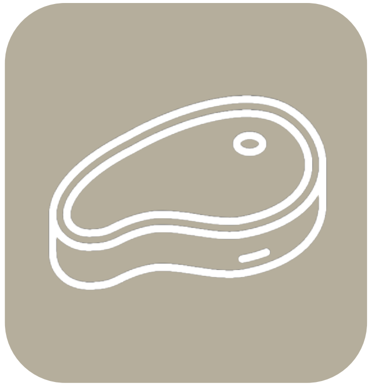
DIETARY GUIDELINES

Mushrooms as a "Third Food Kingdom"?

Plants/ Botany



Animals/ Zoology

Fungi/ Mycology

"Mushrooms' nutrient and culinary characteristics suggest it may be time to revaluate food groupings and health benefits in the context of 3 separate food kingdoms"

– Feeney et al Nutrition Today, 2014

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Emphasising a food as unique in Dietary Guidelines has precedence

“There is precedent for recognising unique foods as the DGA states ‘beans and peas are unique foods,’ and their nutrient profile enables them to be counted both as a vegetable and a protein food.”

- Feeney *et al.*, Nutrition Today, 2014

2013 ADG

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Yet very few are talking about it

Kris Kasperkiewicz ANutr
@WholesomeKris

Dietary guidelines distinguish animal-based and plant-based, with a push toward the latter.
But rarely include fungi-based!
#nssheff22

5:35 PM · Jul 14, 2022

Hannah Theobald, PhD, RNutr @NutritionHannah · Jul 14, 2022

There is a song case fir a third protein group - fungal protein argues Dr Emma Derbyshire at @NutritionSoc #NNSummer22 #NSSheff22 #fungalprotein #mycoprotein

2 5

Dietary Guidelines globally still class mushrooms as a vegetable, and rarely acknowledge fungi

US:
- Mushrooms = a vegetable.
- 5 different vegetable groups: dark green, red and orange, beans, starchy, “other”.
- Mushrooms are part of “other” vegetables.
- No mention of fungi.

Australia:
- No mention of mushrooms or fungi.
- Included in visual summary and modelling as a vegetable.

New Zealand:
- No mention of mushrooms.
- Only mention of fungi is under food safety: “Pathogens can be bacteria, fungi, parasites, or viruses”.

Canada:
- Mushrooms = a vegetable.
- No mention of fungi.

Brazil:
- Mushrooms = natural / minimally processed food.
- Acknowledges mushrooms as a fungi: “mushrooms and other fungi”.

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In ADG, mushrooms sub-classified as an "other" vegetable

2.2 Enjoy plenty of vegetables, including different types and colours, and legumes/beans, and enjoy fruit

Green & Brassica

Orange

Starchy

Legumes

Other

Tomato
Beetroot
Celery
Cucumber
Avocado
Capsicum
Garlic
Onion
Eggplant
Mushroom

"To increase the variety of vegetables consumed, a 30% increase in green and Brassica vegetables, 140% in red- and orange-coloured vegetables, and 90% in other vegetables, would be optimal." - ADG

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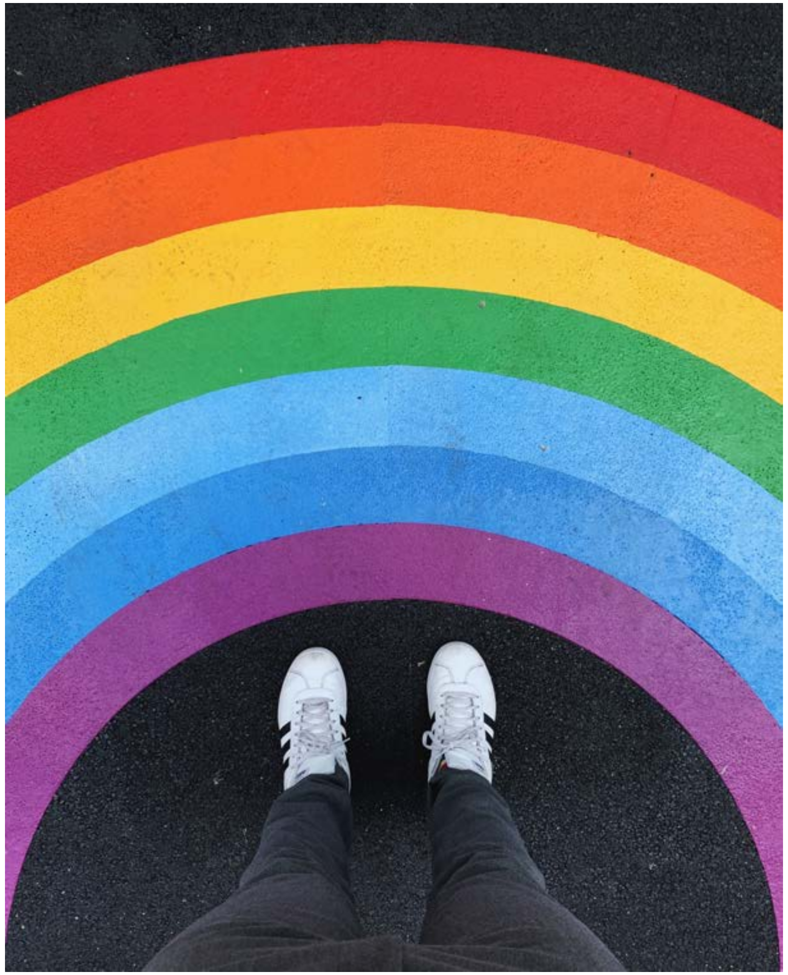
Unlike green and orange/red, white vegetables are not emphasised nor have a distinguishing nutrient



"US dietary guidance encourages … at least 1 serving of a dark green and 1 orange vegetable daily. However, no such recommendation exists for white vegetables"

- Weaver, Adv Nutr, 2013

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While mushrooms are not currently an emphasise in Dietary Guidelines, they do support themes that are…

"A diet rich in plant-based foods and with **fewer animal source foods** confers both improved health and environmental benefits."

- EAT-Lancet report

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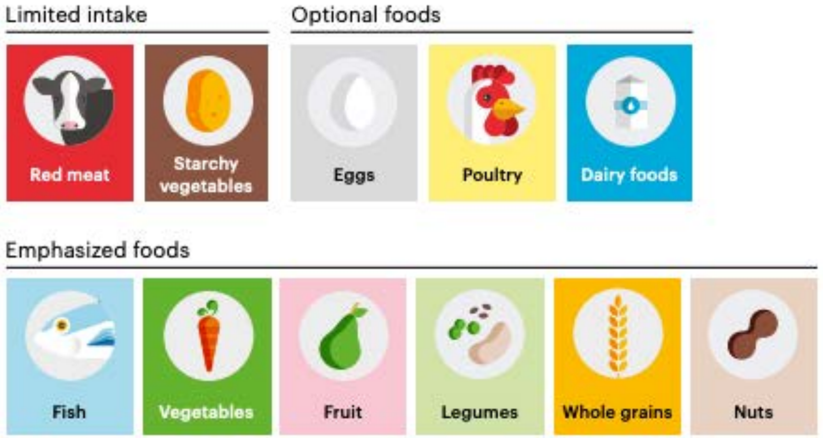
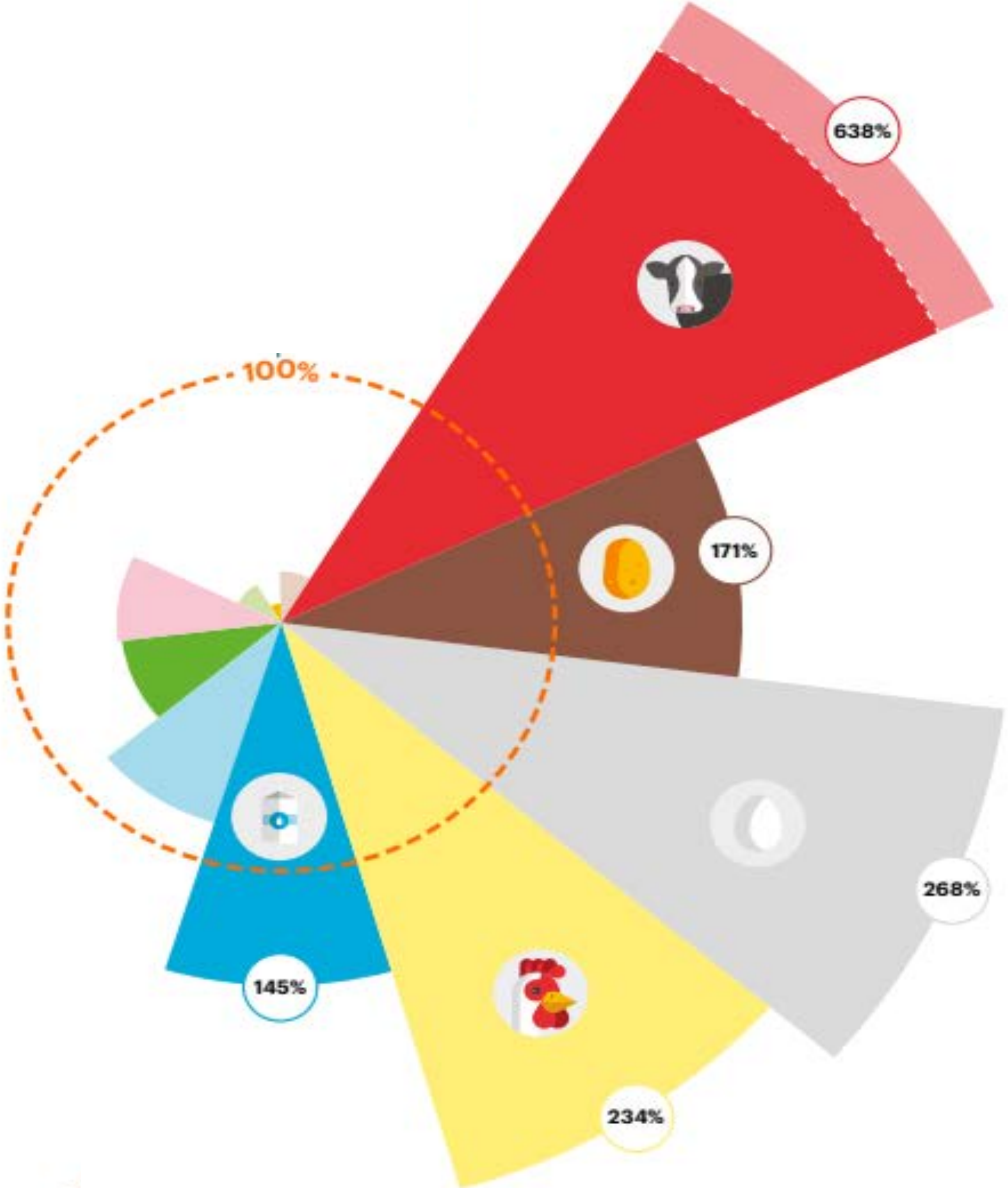
Transformation to healthier diets will require substantial dietary shifts



But few practical solutions have been offered for decreasing meat consumption.



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Mushrooms as a practical strategy for this shift?

"In the average Australian diet, red meat and poultry contributed 73% to the total servings of meat and alternatives, compared to 33% and 10% for the Australian Dietary Guidelines and Planetary Health Reference Diet respectively."

- Hendrie *et al.*, BMJ Public Health 2022

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Nuts and seeds are **not** nutritionally equivalent to meat yet **are** a meat alternative in the ADG

Meat & Alternatives	Nuts & Seeds
Distinguishing/key nutrients	
Zinc	Magnesium
Iron	Linoleic acid
Vit B12	Potassium
LCn3	Vit E

"Nuts & seeds have a different protein to energy ratio compared with other components of the meat's groups, **so for modelling purposes they were made into a separate group.**"

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Are protein & the "essential" amino acids overvalued?

Protein NOT a distinguishing/key nutrient for meat & alternatives:

- ✓ Available from several food groups
- ✓ No evidence of deficiency or borderline intakes in AU

Harvard Health @HarvardHealth

Two findings published in 2020 suggest that longevity is associated with either increasing plant protein consumption or replacing animal proteins, especially red meat and eggs, with plant protein: bit.ly/3j4F2iZ #HarvardHealth

David Sinclair @davidasinclair

Food for thought! Branched chain amino acids (BCAAs) such as leucine are abundant in meat, dairy & #fitness products. New study in mice shows BCAAs can change serotonin brain levels to increase hunger & reduce lifespan. tinyurl.com/y27c8zkz #lifespan #Health #workout

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"Substituting mushrooms for meat would increase … intake of vegetables, fiber, and non-animal protein."

- Hess. Mushrooms, Snacks and Dairy Foods. 2018

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Mushrooms lack an established serve size in Dietary Guidelines

Relies on default serve size for vegetables = ½ cup

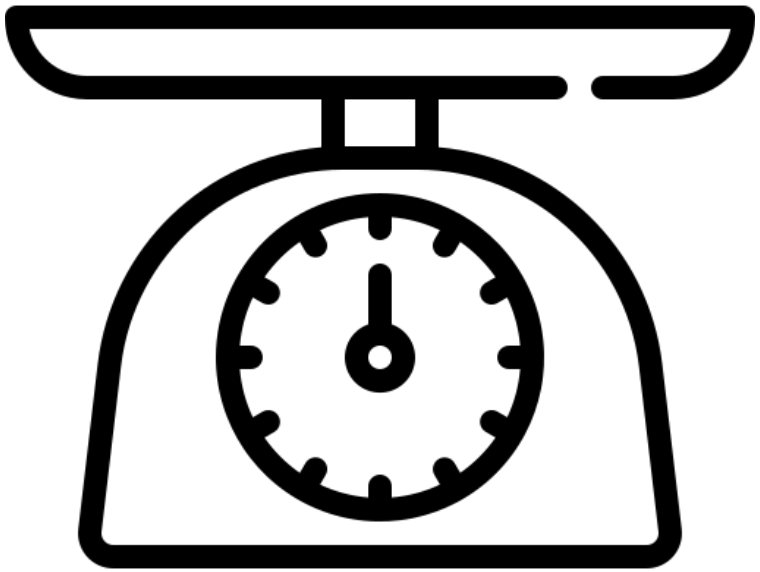
- But this can range from 75 grams to 84 grams to 100 grams!

Opportunity to include specific serve size for mushrooms in ADG?

- Veggies examples provided do not include mushrooms.

Opportunity to increase serve size if a meat alternative?

- In ADG, legumes have a different serve size as a meat replace (1 cup, 150g) vs. as a vegetable (1/2 up, 75g)



Intake = just 21 grams/day among mushroom consumers (US)

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STAKEHOLDER, INDUSTRY & CONSUMER

Mushrooms are increasingly normalised as a meat alternative

CHEEKY BOWL

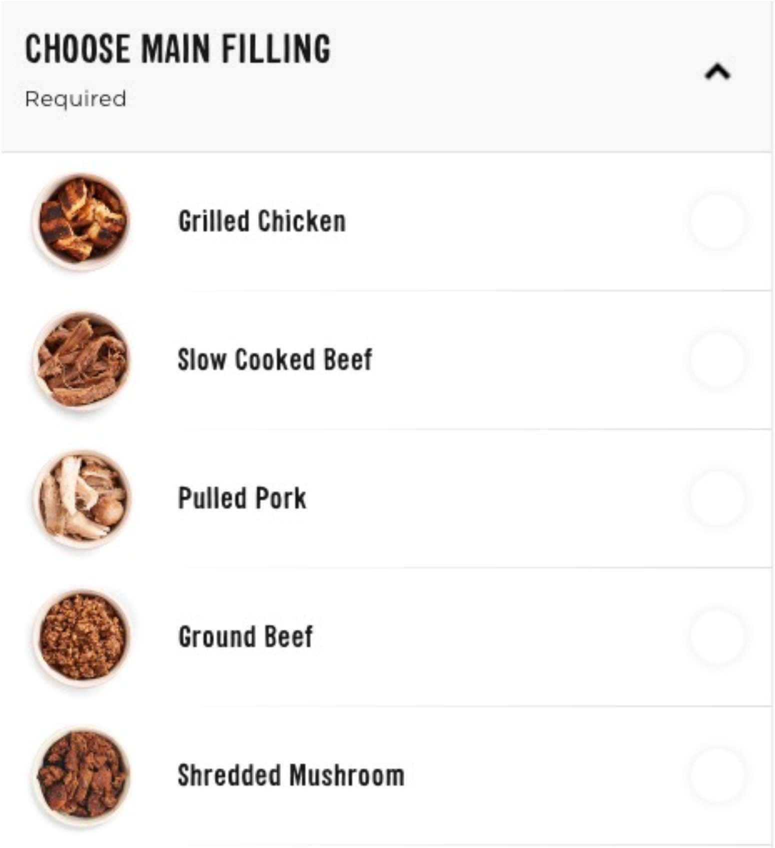
1: CHOOSE A PROTEIN

1 protein included (ask about adding another serve to your bowl)

salmon	S / 17	**R / 20.9**	prawn	S / 17	**R / 20.9**	wagyu beef	S / 20	**R / 23.9**
tuna	S / 19	**R / 22.9**	chicken	S / 15	**R / 18.9**	pork gyoza	S / 15	**R / 18.9**
kingfish	S / 19	**R / 22.9**	tofu	S / 14	**R / 17.9**	mushrooms	S / 15	**R / 18.9**

"Consumers understand food-based terms (e.g. meat & alternatives) better than nutrient-based terms (e.g. protein)."

GUZMAN Y GOMEZ



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Meat alternative category continues to grow

$7.4b

The retail market for plant-based foods is worth $7.4 billion, up from $6.9 billion in 2020.

6%

Plant-based food dollar sales grew 6 percent in the past year.

54%

Plant-based food dollar sales grew 54 percent in the past three years.

3x

Plant-based food sales grew three times faster than total food sales in 2021.

2021 sales data, US, Good Food Institute

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But there are question marks about their healthiness

Meat alternatives might not be so healthy

New research shows most plant-based meat alternatives are high in sugar and low in fortified micronutrients.

"Most meat analogues were also ultra-processed and few are fortified with key micronutrients found in meat."

- Melville et al, Nutr & Diet, 2023

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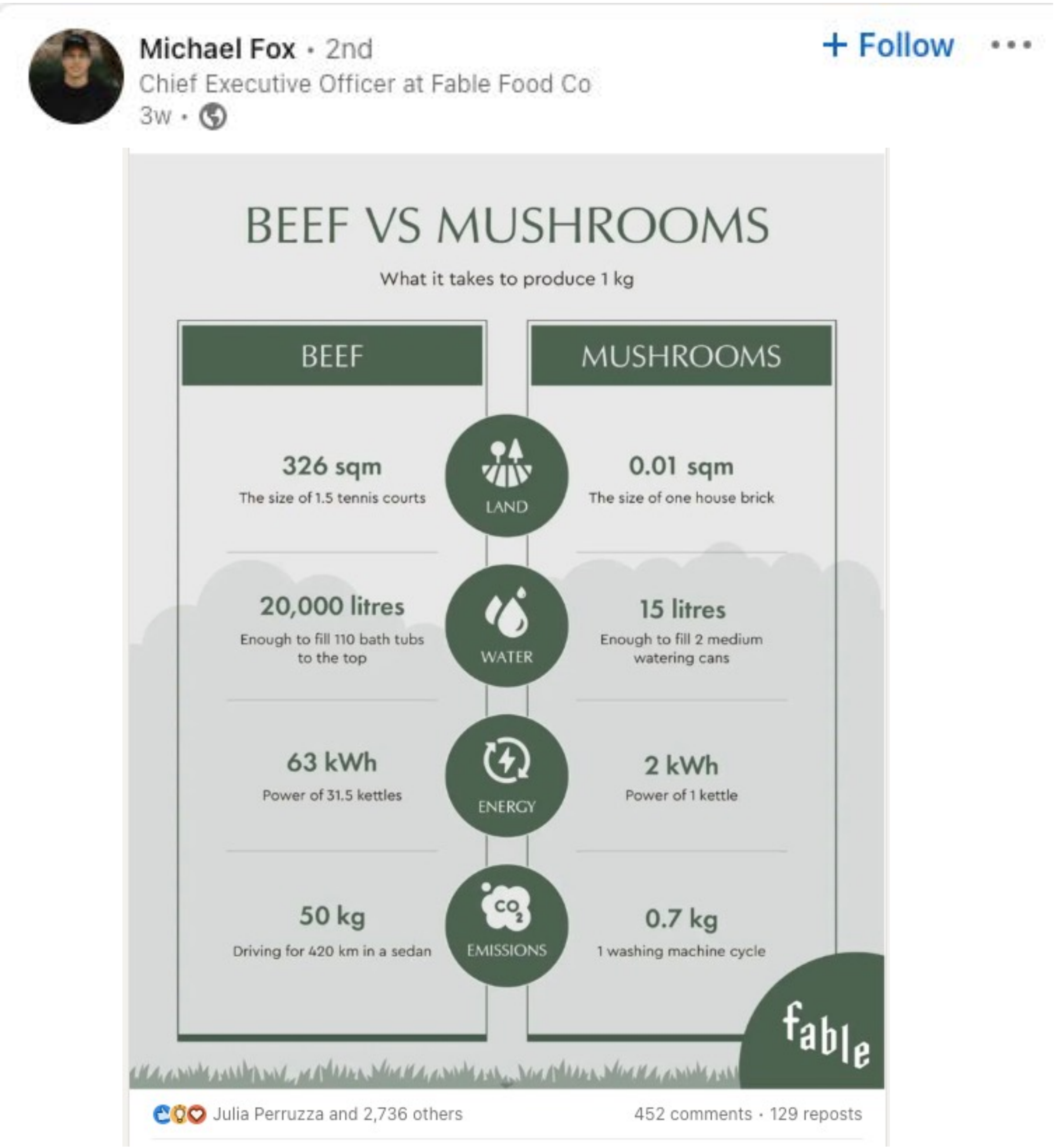
Michael Fox • 2nd
Chief Executive Officer at Fable Food Co
3w •
+ Follow
BEEF VS MUSHROOMS
What it takes to produce 1 kg
BEEF
MUSHROOMS
326 sqm
The size of 1.5 tennis courts
LAND
0.01 sqm
The size of one house brick
20,000 litres
Enough to fill 110 bath tubs to the top
WATER
15 litres
Enough to fill 2 medium watering cans
63 kWh
Power of 31.5 kettles
ENERGY
2 kWh
Power of 1 kettle
50 kg
Driving for 420 km in a sedan
CO_2
EMISSIONS
0.7 kg
1 washing machine cycle
fable
Julia Perruzza and 2,736 others
452 comments • 129 reposts

Replacement of meat for mushrooms associated with better health

Recent prospective cohort study:

"Consuming 1-serving of mushrooms per day instead of 1-serving of processed or red meats was associated with lower risk of all-cause mortality (adjusted HR = 0.65; 95% CI: 0.50–0.84)."

– Ba et al, Nutrition Journal, 2021

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Consumer insights suggest mushrooms = more than just health

1

Mushrooms = less cost

A 50:50 beef: mushroom blend saves 20% on the food cost. This increases to 33% for a 20:80 blend.

2

Mushrooms = more appeal

Substituting meat with mushrooms increases perceived flavour intensity and improves acceptance of vegetable protein by meat lovers

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VITAMIN D

Should the ADG start emphasising vitamin D?

"**The only nutrient that was consistently low compared to the AI was vitamin D**. However as the AI assumes little exposure to sunlight and those people who have moderate exposure to sunlight are likely to have lower requirements for vitamin D, this may not be problematic.

Nevertheless, there is emerging evidence of vitamin D deficiency in Australia in the general population, and **this issue may need to be further investigated and addressed**."

- ADG Dietary Modelling, 2011

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The US Dietary Guidelines recognise the vitamin D problem, but not mushrooms as a solution

- “In no modelling scenario did the amount of vitamin D meet the RDA or the EAR”.
- Several hypothetical models were explored. The only option that brought vitamin D intakes to the RDA level encouraged seafood choices with the highest quantities of vitamin D, fortification of dairy and juice, and the potential fortification of grain products. But this limits seafood choices to those not normally consumed.
- Supplements recommended by a health professional may be required “in many cases”.
- List of dietary sources of vitamin D provided; **mushrooms not included**.

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The vitamin D problem is a hot topic that requires urgent attention in AU

In the last 10 months alone:

- ✓ Mean vit D intake in Australians estimated using new analytical vitamin D food composition data. **More than 95% had intakes below the IOM EAR** of 10 ug / day (Mean intakes = 1.84 – 3.25 ug/day).
- ✓ A modelling study of the fortification of vitamin D to milk increased mean intakes to 4.9 ug/day – a meaningful increase but **still well below the EAR**.
- ✓ Experts are calling for a **more comprehensive strategy** as part of a national nutrition policy.

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Creating pathways to success

STEP 3

What are the key themes?

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Landscape Themes

HIGHER SERVE SIZE NEEDED

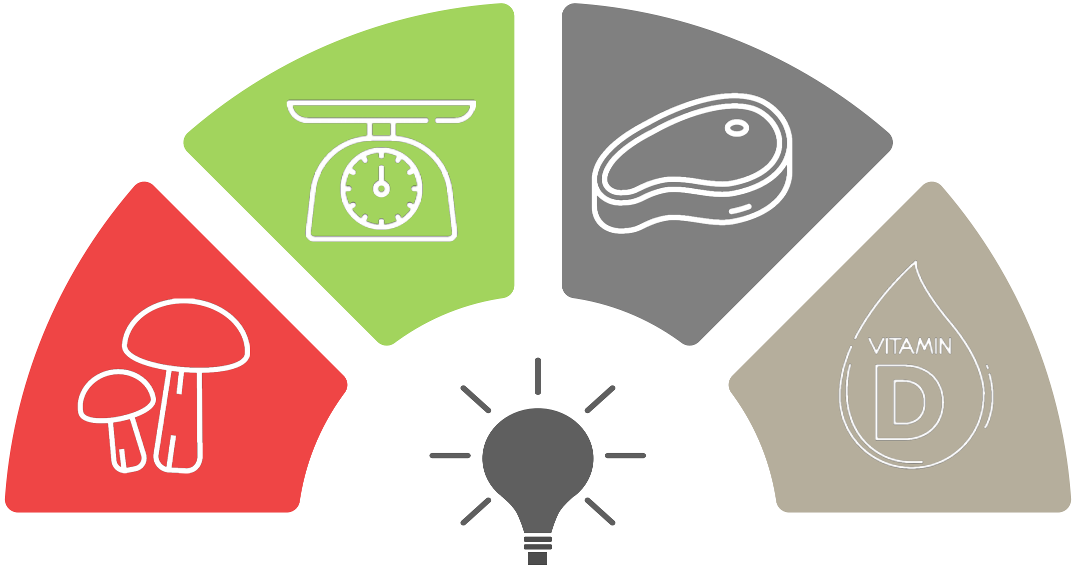
- Mushrooms are not mentioned in Dietary Guidelines
- No standardised serve size
- Cooked vs raw affects visual serve size
- All health effects are ≥ 100g
- Content claims are based on serve size: modelling at higher serve can increase nutrition provided
- Is a 75 g serve too low?

REPLACEMENT FOR MEAT & SALT

- Culinary benefits: umami flavour, palatability, meaty texture
- Cooking replacement for meat
- More sustainable vs. both meat and vegetables + animal welfare
- Trend for movement away from animal foods
- At least as nutritious as meat; potentially superior
- Established health benefits when replacing meat; this is recommended by health authorities

DISTINCT NUTRITION

- Mushrooms do not meet the key distinguishing nutrients of any current food group
- Distinct nutrition profile vs all other vegetables
- Biologically unique: fungi food kingdom
- Unique bioactive profile, linked to health benefits



LACK OF VITAMIN D

- Inadequate supply via sunlight or supplements
- Diet can play a major role to address deficiency but only with mushrooms or food fortification
- Only vegan source of vitamin D
- Vitamin D needs to be a distinguishing nutrient for meat & alternatives

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What are the potential pathways?

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Potential Pathways to success

New fungi food group

Food groups revamped based around food kingdoms, with the introduction of mushrooms/fungi as a new group.

Sub-category within vegetables

Mushrooms/fungi as a sub-category within vegetables. To be called out explicitly in the guideline.

Meat alternative

Mushrooms reclassified as a healthy, sustainable meat alternative. Could remain a vegetable as well (like legumes).

Solution to the vit D problem

Acknowledge that the only way to meet vit D needs through diet is via UV-mushrooms.

Develop the rationale and substantiation for mushrooms to be specifically recommended in the ADG.

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New fungi food group

Plus	Minus	Interesting
• Good reasons across nutritional science, biological, and culinary that mushrooms are unique:	• The fungi food group would primarily contain mushrooms: “group” or “food”?	• Need to create a groundswell, as not a lot of people talking about this currently
• Mushrooms provide some but not all distinguishing nutrients from each food group	• Many other foods are nutritionally unique and still fit within an existing food group	• Big opportunity to start the dialogue
• Only food with potential to meet vitamin D needs	• Fungi foods are nutritionally diverse (mushrooms vs yeast); e.g. yeast does not provide vitamin D, so limited reason to group together nutritionally	• A lot of people are talking about vitamin D but not mushrooms: opportunity to create a novel conversation
• Big changes have been implemented previously e.g., Canada changed the meat/alternatives food group name to protein, and Australia has a reputation for doing things differently globally	• Addition of new food group is a big change – is it too late and unachievable?	• Should the food group be mushrooms or fungi? Fungi helps people to disassociate from vegetables but has negative connotations.
		• Would need a food group definition of fungi

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Sub-category within vegetables

Plus	Minus
• Likely easier to achieve vs mushrooms/fungi as own food group.	• Creates increased complexity.
• Possible stepping stone to achieving mushrooms/fungi as new food group, as helps with the differentiation story.	• Could also be a hindrance rather than a stepping stone, by affirming the place of mushrooms in the vegetables group.
• There is an established serve size.	• Serve size will likely remain 75 g, which is too low for many nutritional benefits.
	• Will not solve the vitamin D problem.
	• Mushrooms will still be “a vegetable” and associated with vegetables; guidelines communicate variety of vegetables but not the specific types.
	• Vegetables have a negative/unpleasant connotation.

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Meat alternative

Plus	Minus	Interesting
• Huge marketing opportunity as a substitute for minced/ground meat.	• Comparing meat to mushrooms is a hurdle; mushrooms are not a source of protein or iron at 150 g serve so may be automatically rejected.	• If serve size was increased (200 g), mushrooms may become a source of protein (> 5 g; based on global average composition).
• Already being considered by consumers and industry.	• No precedence in Dietary Guidelines to date.	• There may be different serve sizes, based on whether mushrooms are consumed on their own vs. as a blend with meat/alternatives.
• More achievable and practical vs own food group, and helps to improve health; closes the behaviour intention gap for reducing meat intake with a sustainable angle		
• Increased serve size of 150g (same as legumes)		
• Improves the taste of food, meaning people are more likely to have it; gives people choice		
• Can be modelled separately, as done for nuts & beans.		
• Potential stepping stone to a new food group.		
• Mushrooms are closer nutritionally to animal foods vs vegetables		

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Vitamin D

Plus	Minus	Interesting
• Innovative and unique angle that the dietary guidelines have not taken to date.	• No precedence in Dietary Guidelines to date.	• Underpins/provides some of the rationale for mushrooms being their own food group.
• Only food that can solve for the vitamin D problem.	• Mushrooms (non-UV) do not solve the vitamin D problem by themselves.	• There is an opportunity to establish more up-to-date vitamin D content for retail mushrooms.
• The majority (80%) of the AUS population consume mushrooms.	• Most people are not consuming UV-mushrooms and it may be difficult for industry to UV-expose all mushrooms.	• There is an opportunity for industry to expose all mushrooms to UVB as the status quo.
• Comes with a package of nutrition whilst being as effective as a supplement.		
• Helps to shift the dial on healthier diets as well as vitamin D intake.		
• On trend with a “plant-based diet” (less animal foods), including sustainability angle.		
• Sunlight is not the answer for most people to meet vitamin D needs, due to dark skin, the need to cover up etc.		
• Perhaps even more than 1 in 4 may lack vitamin D today.		
• Opportunity for mushrooms to OWN the vitamin D message.		

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Strategic solutions

STEP 4

How should each pathway be assessed?

Supported by significant scientific evidence

Makes practical sense within the context of the ADG

Alignment with industry strategy

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Important to keep in mind that while the mushroom science is exciting, it is also limited

Current food groups consist of a number of different foods that provide key/distinguishing nutrients (not easily obtained from other food groups) and have well documented health benefits.

This contrasts to mushrooms:

- ✓ Singular food (not a number of different foods).
- ✓ All nutrient needs (except for vitamin D) can currently be met without the consumption of mushrooms.
- ✓ Other than UV-exposed mushrooms increasing vitamin D status, the health benefits of mushrooms are based on limited evidence.

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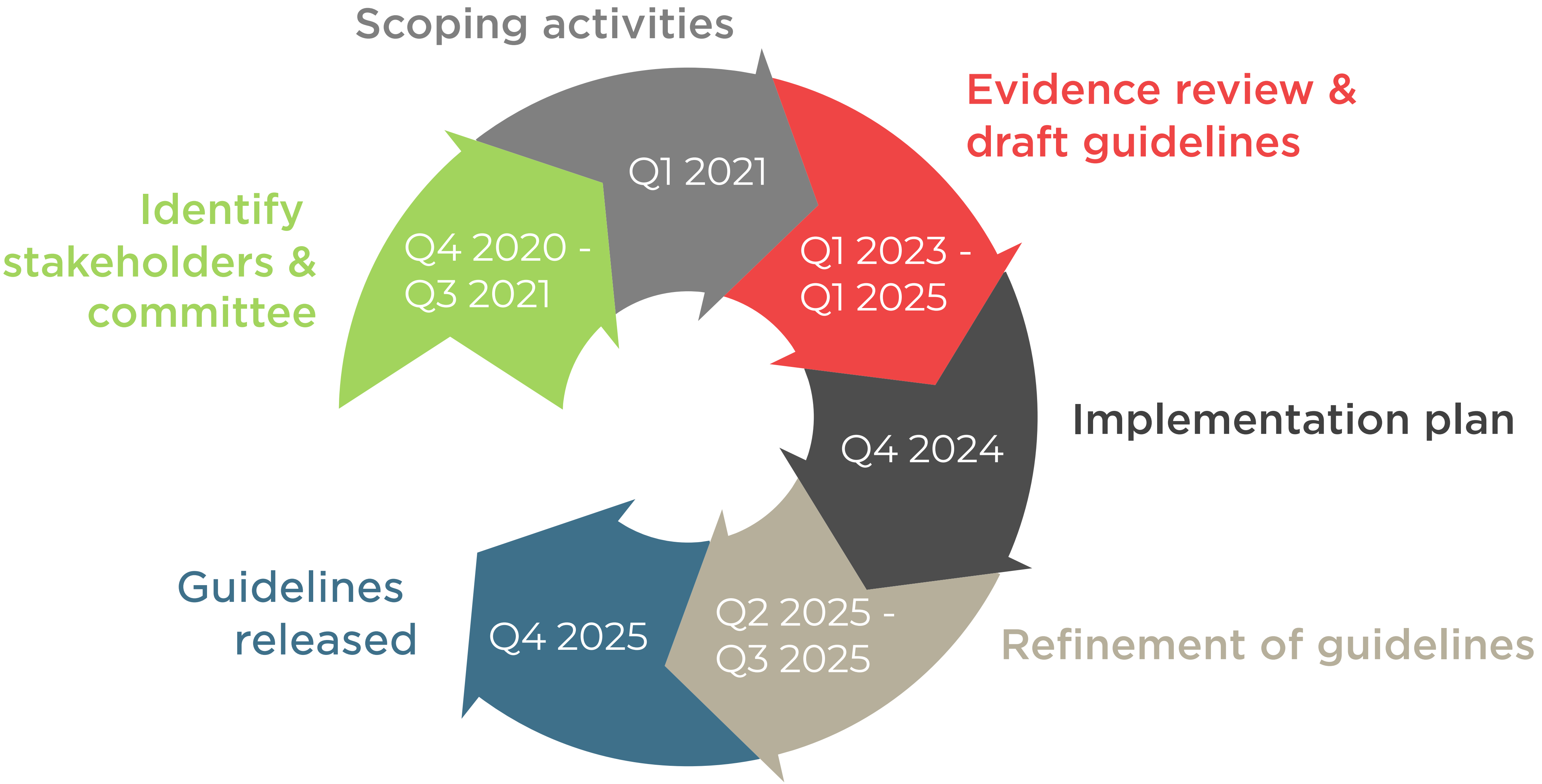
And that the ADG update is a lengthy process that we are entering into late



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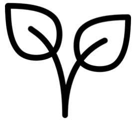
Pathway assessment

	Significant scientific evidence	Makes practical sense	Alignment with industry strategy	Total score	Rank
New fungi food group 	2/5	0/5	5/5	7/15	2
Sub category within vegetables 	3/5	4/5	3/5	10/15	1
Meat alternative 	2/5	3/5	1/5	6/15	3
Solution to the vitamin D problem 	N/A - will be a key component across all pathways.				

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Assessment and recommendation

Assessment:

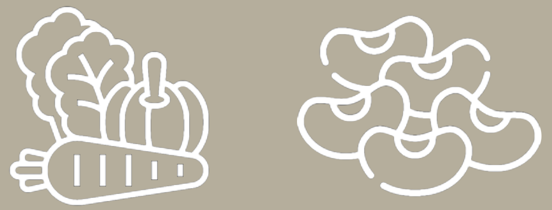
While a new fungi food group aligns with the industry strategy, there is **low likelihood** of success for the current ADG update.

Recommendation:

The focus for this ADG update be on mushrooms as a **sub-category within vegetables group** in the ADG, as while it is still difficult to achieve, it has a greater likelihood of success.

Mushrooms were also chosen over fungi as fungi foods are not nutritionally equivalent and it is more aligned with the industry strategy.

From: “Eat plenty of vegetables and legumes/beans.”



To: “Eat plenty of vegetables, **mushrooms**, and legumes/beans.”

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How the issues raised with pursuing a sub-category within vegetables will be addressed

Issue raised in workshop	Comment / How it will be addressed
• Creates increased complexity.	• There will be far more clarity on dietary guidance for mushrooms.
• Could also be a hindrance rather than a stepping stone, by affirming the place of mushrooms in the vegetables group.	• By having mushrooms as its own sub-category, it is a key step forward to differentiation.
• Will not solve the vitamin D problem.	• A key argument for the differentiation as its own sub-category is to help solve the vitamin D problem.
• Mushrooms will still be “a vegetable” and associated with vegetables; guidelines communicate variety of vegetables but not the specific types.	• By having mushrooms as its own sub-category, it can differentiate from other vegetables.
• Vegetables have a negative/unpleasant connotation.	• By having mushrooms as its own sub-category, it can differentiate from other vegetables. Thinking on meat alternative can be applied in this context.
• Serve size will likely remain 75g, which is too low for many nutritional benefits.	• This will not be addressed. Recommend that serve size be reviewed as a separate project.

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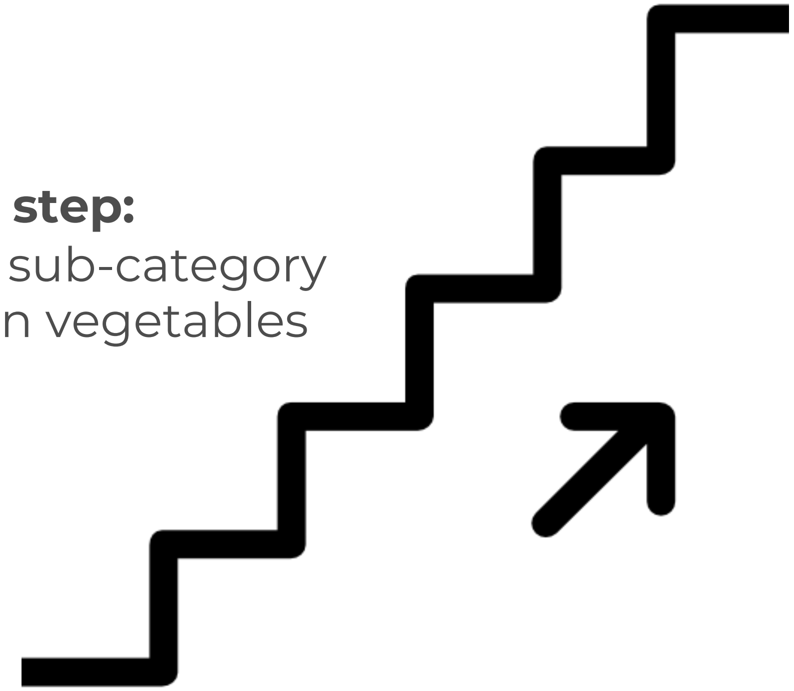
This is a key step forward to its own food group classification

“Holy Grail”:
Own food group

Next step:
Own sub-category
within vegetables

Current step:
“Other” vegetable



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7 recommendations to achieve mushroom classification as its own food group

1. Be the solution to vitamin D

Work with growers to establish how mushrooms can be UV-exposed as standard practice.

2. Clear serve size

Provide clarity on mushroom quantity for nutritional modelling and dietary guidance.

3. Quantify bioactive needs

Strengthen the case for the impact of mushrooms in meeting key nutritional requirements.

4. Mushroom modelling

Demonstrate how mushrooms are important for meeting nutritional shortfalls.

5. Develop + validate FFQ

Enable mushrooms to be more widely studied in observational studies (separate to vegetables).

6. Invest in research

Grow the evidence-base for mushrooms and health across RCTs and epidemiological studies.

7. Continuous advocacy

Communicate mushrooms uniqueness with focus on vitamin D.

Strategic Solutions to success

Collate the science

Part 1

- Scope of the literature for key proof points to support new mushroom positioning in ADG.

Dietary Modelling

Part 2

- Modelling to determine the impact of this change on nutrient intakes.

Publication

Optional add on

- Publish an opinion piece that summarises the science collation and dietary modelling.

Develop the rationale and substantiation for mushrooms to be specifically recommended in the ADG

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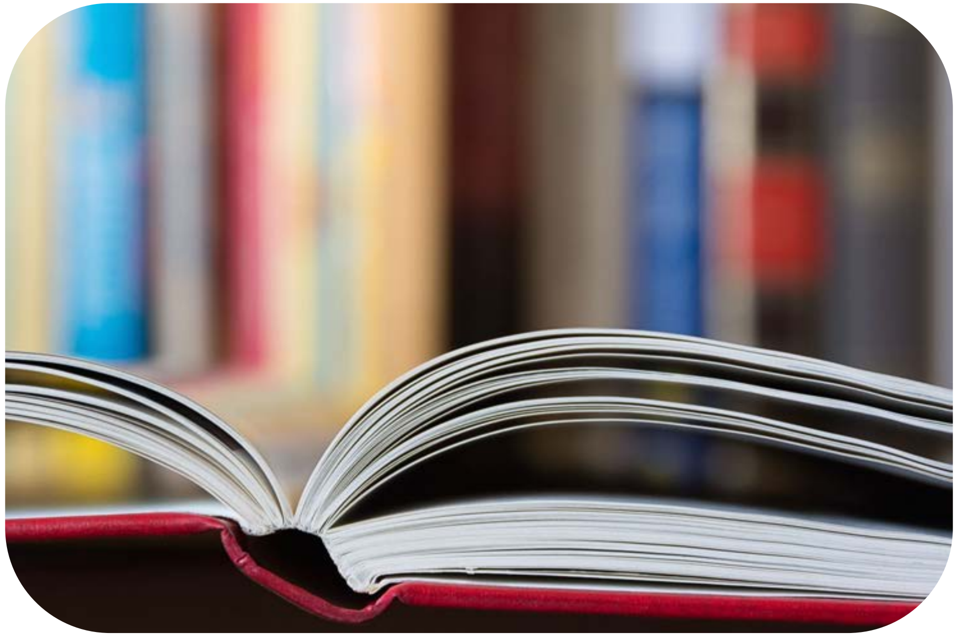
Part 1: Literature scoping

What we know: Mushrooms are viewed within the Australian Dietary Guidelines as a component of the vegetables core food group, within the “other” sub-category, alongside tomatoes, onions, and celery. The development of a clear and robust evidence-based rationale for the differentiation of mushrooms requires a comprehensive scope and integration of the scientific literature.

What it is:

- A comprehensive scope of the scientific literature on the 4 key proof points for mushroom as a sub-category of vegetables:
    - Biologically distinct
    - Unique nutritional profile and health effects
    - Unique culinary properties
    - Important contribution to nutrient intakes (including vitamin D)
- Consideration of variety of mushroom types available will be included to help strengthen the case for mushrooms as its own sub-category.



Includes:

- A comprehensive summary of the scientific evidence.
- Evidence-based messages and rationale to inform submission.

Outcome:

- A clearly presented summary of the scientific evidence supporting the differentiation of mushrooms as a separate sub-category within the vegetables core food group.
- Provides the foundation for submission to NHMRC.

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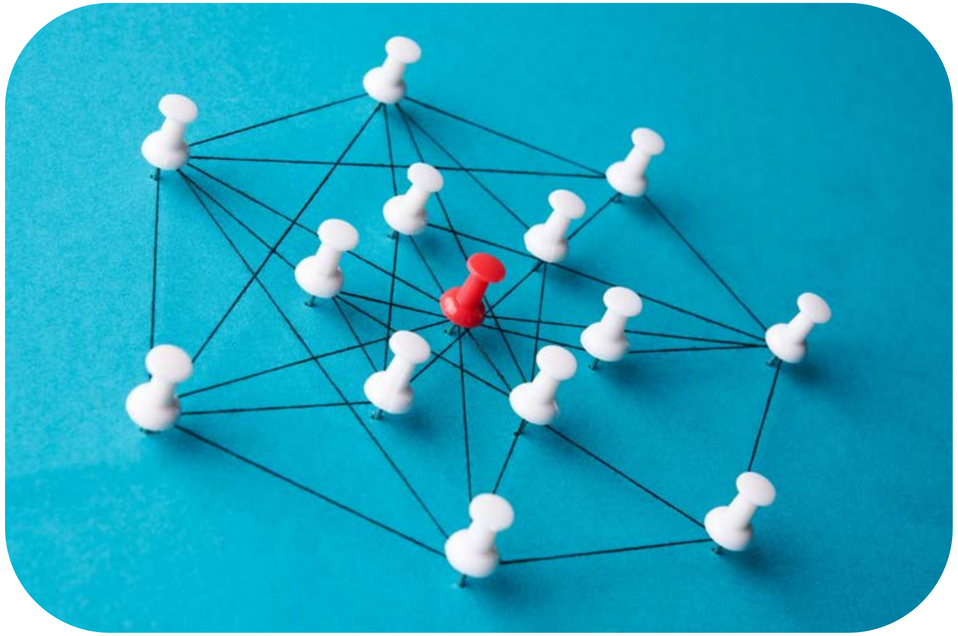
Part 2: Dietary modelling

What we know: The food groups and their recommended intakes in the ADG were established using mathematical modelling to create Foundation Diets for each age and sex. Mushrooms currently sit within the “other” sub-category of the vegetables core food group. What would happen to the nutritional composition of Foundation Diets, particularly vitamin D, if mushrooms left the “other” group and sat on their own as a separate sub-category within vegetables?

What it is:

- Mathematical modelling to determine the nutritional impact of recommending that one serve of the vegetables food group should be mushrooms, with a spotlight on vitamin D, as a proof-of-concept approach.
- Modelling of different scenarios to determine the number of serves of mushrooms needed to significantly impact key nutrients (such as vitamin D)



Includes:

- Quantitative estimates on the ability of mushrooms to impact nutrient intakes for each age and sex.
- Understanding of the level of mushroom consumption needed to significantly increase vitamin D intakes.

Outcome:

- The modelling will strengthen the rationale used in the ADG submission.
- The findings of the modelling can be incorporated into a published opinion piece.

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Optional add on: Publication

What we know: There is a strong story to differentiate mushrooms in Dietary Guidelines, but few are talking about it.

What it is:

- Expert narrative review summarising the evidence-based rationale surrounding mushrooms and their inappropriate placement within the Dietary Guidelines, with proposed solutions and call to action for next steps.

Includes:

- Giving a credible voice to the importance of the differentiation of mushrooms for optimal public nutrition and health.
- Strategic thinking to best structure the narrative and authorship for maximum impact.
- Publication in open-access, high impact journal for all to easily access the research, cite, share, and have notable reach.

Outcome:

- Published, credible, and authoritative review with high impact and reach.
- Call to action for next steps, supporting submission.

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Indicative fees

Project Type	Description	Indicative fees (AUD) excl. GST
Literature scoping and dietary modelling	• Comprehensive scope of the scientific literature summarising evidence-based proof points for the differentiation of mushrooms as a separate sub-category within the vegetables food group. • Mathematical modelling to determine the nutritional impact of recommending that one serve of the vegetables food group should be mushrooms, with a spotlight on vitamin D.	Within project scope
Publication (optional)	• Expert narrative review summarising the evidence-based rationale surrounding mushrooms and their inappropriate placement within the Dietary Guidelines.	$16,500 (not including open access publication fee)

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Next Steps and Timings

1. Decision on direction
2. Begin scientific scope and modelling
3. Complete report

Recommended timeline to completion is Monday, 29 May, 2023. This is an extension of 4 weeks to accommodate for the 4 week delay in the NiQ process.

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Acknowledgements

Thank you to the following stakeholders who provided expert consultation:

- Glenn Cardwell
- Greg Seymour

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Thank you

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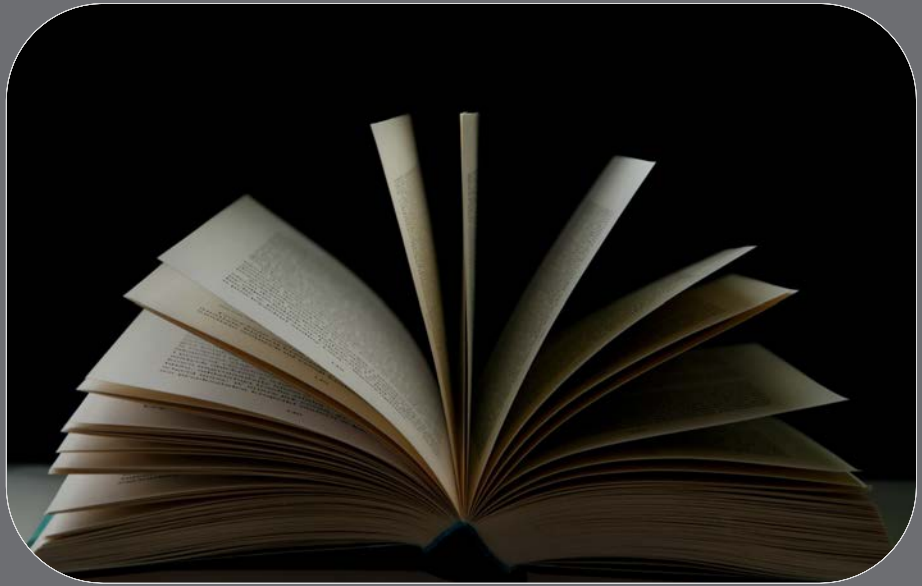
Appendices



Phase 1: Brainstorming Potential Key Messages

Category	Key Message
1. Establish fungi as unique kingdom in the ADG	Highlight unique biology – growing, makes vit D, definition vs. animal/plant, differentiation from plants
	Unique growing conditions
2. Separate fungi (mushrooms) from vegetables and other food groups	Highlight unique nutritional properties – incl. vit D
	Promotes an increased diversity of foods and fibre and phytonutrient sources in the diet
	Highlight unique culinary properties
3. As a result, establish fungi (mushrooms) as a "superfood"	Unique health effects incl gut microbiota
	Mushrooms boost the benefits/value of a mince meal and reduce meat consumption
	Sustainability/environment story

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Mushrooms in the Australian Dietary Guidelines: Scientific evidence report

Prepared for:

Australian Mushroom Growers Association

May 2023

Prepared by:

Nutrition Research Australia Pty Ltd

Contents

Executive Summary

The Australian Dietary Guidelines (ADG) provide authoritative advice about healthy eating and are under review, due for update in 2025. In the current guidelines, mushrooms are categorised in the 'vegetables and legumes/beans' food group but are not biologically a plant (vegetables or legumes/beans) and consequently have unique nutrition, culinary, and health properties.

The Australian Mushroom Growers Association, on behalf of Hort Innovation, commissioned Nutrition Research Australia (NRAUS) to support with the strategic direction and collation of the scientific evidence to advocate for the repositioning of mushrooms in the Australian Dietary Guidelines based on their unique nutrition credentials, via a phased approach (1. Decision on strategic direction; 2. Collation of scientific evidence; 3. Translation of science to support submission to the ADG). In Phase 1 of this project, a decision was made to advocate for mushrooms to be its own subcategory within a revamped 'vegetable, legumes/beans, and mushrooms' food group. This report is Phase 2 of the project and aims to collate the evidence to support this repositioning via a literature scope and dietary modelling.

Key findings

- Mushrooms are not vegetables and belong to a distinct biological kingdom, fungi.
- Mushrooms provide a nutrient and bioactive package that is largely different to the vegetables core food group. This includes niacin, vitamin B5, biotin, vitamin D, copper, phosphorus, selenium, ergothioneine, beta-glucan, chitin, and phytosterols.
- The naturally occurring vitamin D content of mushrooms can be considered as a key distinguishing nutrient that separates it from all other vegetable subcategories in the dietary guidelines.
- Australia has high rates of deficiency and some of the lowest vitamin D intakes globally. It is the most difficult nutrient to meet population needs for in dietary modelling.
- Unlike vegetables, where taste is a common barrier to consumption, mushrooms have a distinct taste profile that includes an umami flavour and meaty texture and can be a meat substitute without compromising on taste or texture. This can help to improve the intakes of key nutrients, such as fibre and potassium, and reduce saturated fat and sodium.
- Unlike vegetables, mushrooms increase in vitamin D content when exposed to UV-light and their consumption has been shown to increase vitamin D status.
- Mushrooms may reduce total cancer risk, particularly breast and ovarian cancers. This is thought to be due to their distinct bioactive profile.
- If mushrooms are modelled as a separate subcategory of vegetables, vitamin D intakes increase substantially. This effect is amplified with UV-exposed mushrooms, where vitamin D needs can be met from as little as 1 to 4 serves per week (depending on demographic group).
- Mushrooms as a separate subcategory of vegetables can also help adults on a vegetarian diet to meet selenium requirements, with no major adverse effects for nutrient intakes. This finding implies that mushrooms may also be able to support the nutritional quality of vegan diets.

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Conclusion

Mushrooms are biologically, nutritionally, and culinarily distinct from vegetables and the reclassification of mushrooms in the Australian Dietary Guidelines to its own subcategory, within a revamped 'vegetable, legumes/beans, and mushrooms' food group, has a beneficial effect on modelled micronutrient intakes in the Australian population, particularly for vitamin D and selenium.

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Contributors

- Carlene Starck, PhD
- Tim Cassettari, BSc, BAppSc, APD
- Flavia Fayet-Moore, PhD, APD, RNutr, FASLM

Glossary of Terms

A glossary of terms used throughout the report is provided in **Table 1.**

Table 1. Terminology used within this report.

TERM	DESCRIPTION
Adequate Intake (AI)	The average daily nutrient intake level based on observed or experimentally-determined approximations or estimates of nutrient intake by a group (or groups) of apparently healthy people that are assumed to be adequate. Used when an EAR (and therefore RDI) cannot be determined because of limited or inconsistent data.
Antioxidant	A compound that inhibits oxidation by reducing the activity of or removing free oxygen radicals in the body. Excessive oxidation leads to oxidative stress and inflammation.
Australian Dietary Guidelines (ADG)	A set of evidence-based guidelines developed for the Australian population providing up-to-date advice about the amount and types of foods needed for health and wellbeing and to reduce the risk of chronic disease.
Bioactive compound	An organic compound sourced from food with non-nutritional biological activity in the body.
Biological kingdom	The second highest taxonomic rank for the classification of living things. The first taxonomic rank is domain (archaea, bacteria, and eukaryotes). The eukaryote biological kingdoms are plants, animals, fungi, and protists.
Cross-sectional study	A type of observational study that analyses the data from a specific population, or a representative subset of that population, at a specific point in time.
Dietary modelling	Mathematical modelling using an evidence-based baseline diet to estimate the quantitative effect on nutritional composition following an intervention.
Foundation diet	Used for the revision of the Australian Dietary Guidelines in 2013, Foundation diets represented baseline diets, applicable to individuals of the shortest height with the lowest energy requirements only.
Meta-analysis (MA)	Statistical analysis combining the data of multiple independent scientific studies focused on the same question, to generate a quantitative estimate of the scientific aspect being studied. A meta-analysis follows a formal, systematic research design.
National Health and Nutrition Examination Survey (NHANES)	Continuous survey conducted every two years to assess the health and nutritional status of adults and children in the US, using both interviews and physical examinations.
Nutrient Reference Values (NRVs)	The Nutrient Reference Values are a set of recommendations for nutritional intake based on currently available scientific knowledge. Examples of NRVs include the Adequate Intake (AI) and Recommended Daily Intake (RDI).

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TERM	DESCRIPTION
Omnivore diet	Diet containing foods from all food groups, including both animal and plant-based foods, as well as fungi and algae.
Ovo-lacto vegetarian diet	Diet that excludes the animal foods meat, fish, and poultry. It still contains dairy products, eggs, fungi, algae, and all plant-based foods.
Phylogenetic tree	Tree diagram that depicts the evolutionary descent of different organisms based on their genetic sequence. Each node of a rooted phylogenetic tree represents the common ancestor of the descendants that arise from it.
Phytochemicals	Phytochemicals are chemical compounds produced by plants, generally to help them resist fungi, bacteria, and plant virus infections. They are thought to improve human health.
Prospective cohort study	A type of research study that follows group of similar individuals (a cohort) who differ with respect to certain factors under study over time, to determine how these factors affect the rates of a specific outcome or outcomes.
Randomised controlled trial (RCT)	A type of research study where participants are randomly allocated to an intervention group or a control group. RCTs provide the highest possible level of evidence for causality from a primary research study.
Systematic literature review (SLR)	A formal research design that comprehensively and systematically synthesises all available published data of a specific type/s relating to a specific research question.
Umami	Describes a savoury or meaty flavour and one of the five basic tastes.
Vitamin D deficiency	A vitamin D (as 25-hydroxy vitamin D) blood level of less than 50 nmol/L.

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Background

Mushrooms and the Australian Dietary Guidelines

The Australian Dietary Guidelines (ADG) are designed to provide up to date advice about the amounts and kinds of foods to eat for health and wellbeing, based on scientific evidence. The current (2013) guidelines are under review and due for update in 2025.

In the current ADG, mushrooms are categorised in the 'vegetables and legumes/beans' food group. This food group is divided into five subcategories: 'dark green or cruciferous/brassica', 'orange vegetables', 'root/tubular/bulb', 'legumes/beans' and 'other vegetables', with mushrooms placed in the 'other vegetables' sub-category, which includes many of the salad vegetables such as tomato, beetroot, and cucumber.

Mushrooms are not a plant, nor a vegetable, and belong to the fungi biological kingdom, giving them unique nutrition, health, and culinary properties [3-5]. This is not recognised in the current ADG, which may be a missed opportunity to improve nutrient intake and population health.

The Brief

The Australian Mushroom Growers Association, on behalf of Hort Innovation, is advocating for the repositioning of mushrooms in the ADG and commissioned Nutrition Research Australia (NRAUS) to support with the strategic direction and collation of the scientific evidence. The project consists of three phases:

Phase 1: Determine the best strategic pathways to help achieve repositioning in the updated 2025 ADG. This has been completed and a decision was made to advocate for mushrooms to be its own subcategory within a revamped 'vegetable, legumes/beans, and mushrooms' food group.

Phase 2: Collate the relevant evidence to support repositioning in the form of a scientific summary report. This is to include dietary modelling to capture the nutritional impact that such a change would have on key population groups in Australia.

Phase 3: Translation of this science into key messages that will support the mushroom industry with making a submission to the ADG.

This report is **Phase 2**: collation of the relevant evidence in the form of a scientific summary report.

Research Questions

The report addresses each of the following research questions:

1. What is the biological classification of mushrooms and how does this differ to vegetables?

2. What is the nutritional composition and contribution of mushrooms to the diet and how does this differ to vegetables?

3. What is the significance of mushrooms being a source of vitamin D?

4. What are the key culinary properties of mushrooms and how does these differ from vegetables?

5. What are the unique health effects associated with mushroom consumption and how do these differ from vegetables?

6. What is the effect on nutritional intake if mushrooms were to become their own subcategory within the vegetable food group?

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Methodology

The scientific evidence was collated using two approaches:

- **Questions 1-5:** via a scope of the scientific literature.
- **Question 6:** via dietary modelling, based on the approach described for the 2013 Australian Guide to Healthy Eating [6].

An overview of the methodology is summarised in **Figure 1.** Full details, including the search strategy used and description of steps involved in the dietary modelling, are provided in **Appendix 1.**

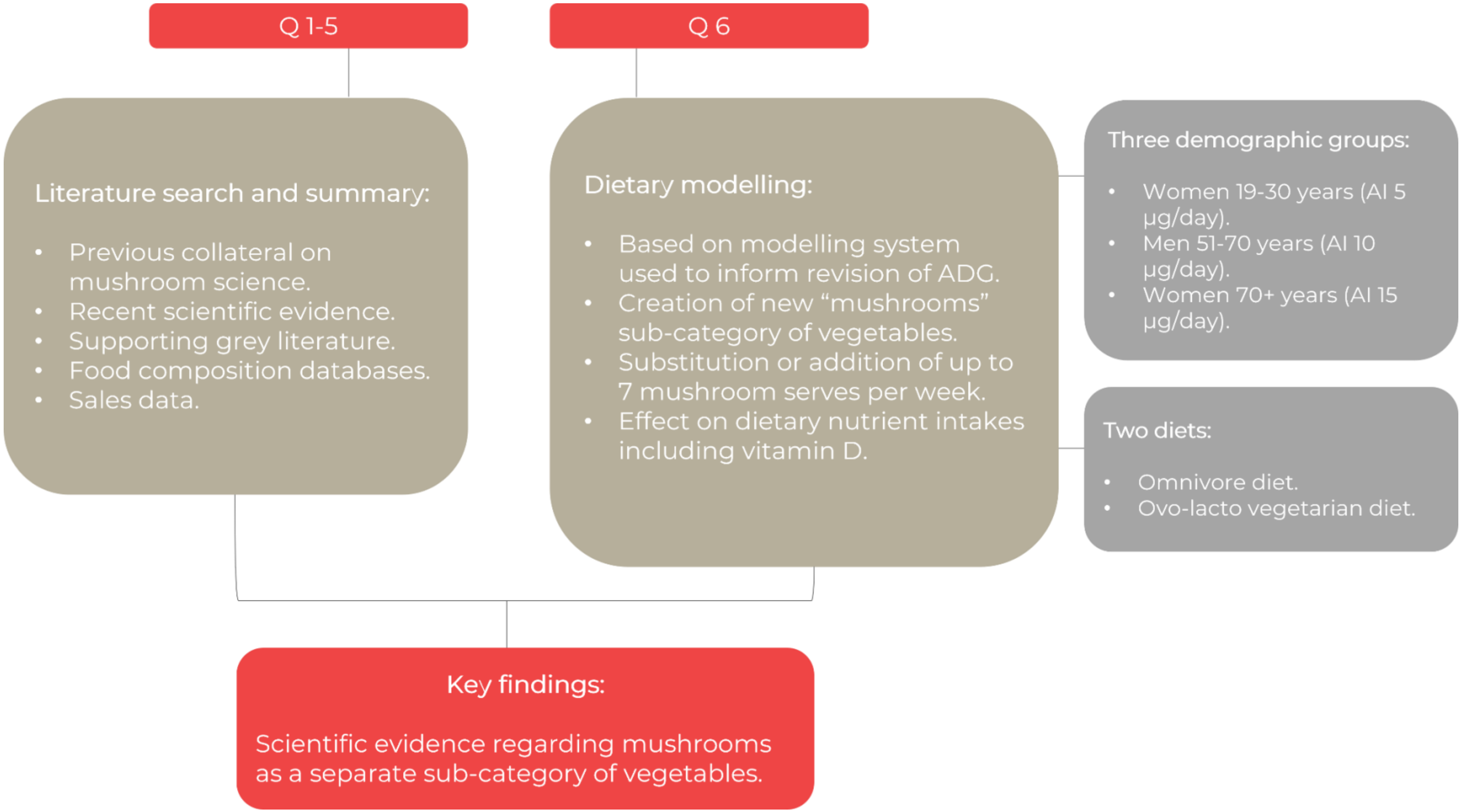

Figure 1. Overview of the methodology used to collate and assess the scientific evidence regarding mushrooms as a sub-category of vegetables. AI, adequate intake.

Results

Q1: What is the biological classification of mushrooms and how does this different to vegetables?

Mushrooms are currently classified as vegetables within the ADG because they are considered nutrient dense, low in kilojoules, and a good source of dietary fibre, minerals, vitamins, and phytochemicals.

In biological terms, however, mushrooms are not vegetables. They belong to the third eukaryotic biological kingdom of fungi, separate to both the animal and plant kingdoms.

A distinct biological kingdom

When viewed in terms of evolutionary relationships and genetic similarity, mushrooms share a more recent common ancestor with animals [7, 8]. While mushrooms, animals, and plants have their own common ancestor, this ancestry is older in time [7]. These relationships are depicted in the phylogenetic tree in **Figure 2**.

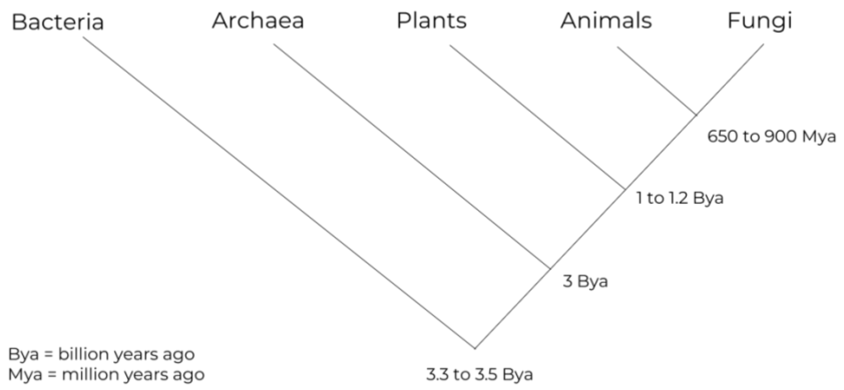

Figure 2. Phylogenetic tree showing the five kingdoms and their relationship, adapted from [9].

The unique role of fungi in the ecosystem

While only 120,000 fungi have been described, there are an estimated 1.5–5 million fungal species [10]. These species are functionally diverse and play a range of important roles in the environment, which together make fungi a unique and essential member of the ecosystem:

- Interconnect biological and ecological organisation to enable the ecosystem to function correctly [10].

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- Interact with and influence the activity of both large eukaryotes (such as animals, humans, and plants) and microorganisms, creating links between micro and macro-organisms and their evolution [10].
- May have had an important role in the initial colonisation of land by eukaryotes (ancestors of plants and animals), and in the appearance and success of land plants and metazoans [11].

Edible mushroom varieties

There are over 2000 varieties of edible mushrooms [2]. The most consumed mushrooms in Australia are:

- Common (*Agaricus bisporus* species) mushroom varieties:
    - White button, the most consumed mushroom in Australia and worldwide,
    - Swiss Brown/Cremini
    - Cup,
    - Flat, and
    - Portobello.
- Exotic mushroom varieties:
    - Oyster (Pleurotus ostreatus),
    - King oyster (Pleurotus eryngii),
    - Shiitake (Lentinula edodes),
    - Enoki (*Flammulina filformis*), and
    - Shimeji (*Hypsizygus tessellatus*).

Differentiating factors from plants/vegetables

A number of morphological, physiological, and nutritional traits make fungi (including mushrooms) unique among all living organisms, including vegetables [7]:

- **Metabolism**: Fungi are decomposers and exist on the breakdown (decay) and absorption of natural material within the environment (including animals and plants). In contrast, plants contain chlorophyll and produce their own food via the process of photosynthesis [2].
- **Structure**: Fungi contain β-glucan and chitin for structural stability. In contrast, plants contain cellulose for structural stability [2].
- **Amino acid production**: Fungi are able to make the amino acid lysine internally, rather than needing to source it from the environment like animals [12].
- **Steroid hormones**: Fungi contain the unique sterol, ergosterol, the precursor to vitamin D_2. While plants contain other phytosterols, ergosterol is not present in plants [2]. The presence of ergosterol enables mushrooms to produce their own vitamin D_2 on exposure to UV-light [13].
- **Nutritional composition**: While vegetables are characterised by a particular set of nutrients, they provide a unique array of nutrients and bioactives that are found across other food groups, including vegetables, grains, and meats [1, 2, 14]. These components are linked to nutritional composition (such as ergosterol converting to vitamin D), health properties (such as beta-

glucan), umami flavour (such as high levels of glutamate and 5'-nucleotides), and meaty texture (chitin)

Why is biological classification important?

Mushrooms are part of a distinct biological kingdom to vegetables (plants), with a unique nutrient, health and culinary profile [2]. Since dietary guidelines group foods based on their nutritional composition and culinary application, this may have important ramifications for where mushrooms are grouped.

Summary: Mushrooms are unique from vegetables biologically

- Mushrooms are not vegetables, but are part of the third biological kingdom, fungi.
- A number of key factors differentiate mushrooms from vegetables and other plant foods, including their metabolism, structural compounds, steroid hormones, and nutrient composition.
- Mushrooms have a unique nutritional composition from vegetables, including vitamin D and other micronutrients found only in 'lean meat and alternatives' or 'cereal grains' food groups.

Q2: What is the nutritional composition and contribution of mushrooms to the diet and how does this differ to vegetables?

The macronutrient (**Table A1**), vitamin (**Table A2**), mineral (**Table A3**), and bioactive (**Table A4**) composition of the most consumed mushroom species available in Australia are provided in **Appendix 2.**

The nutrient composition of Australian mushroom varieties within A*garicus bisporus* was used to compare mushroom nutritional content to that of vegetables.

Mushrooms provide micronutrients that are characterising of the five food groups and not commonly present in vegetables.

The nutritional composition of mushrooms is diverse and represents at least one of the characterising nutrients from each of the core food groups [1, 14]:

- **Vegetables and legumes/beans:** folate and potassium
- **Grain (cereal) foods:** niacin and folate
- **Fruit:** folate and potassium
- **Milk, yoghurt, cheese and/or alternatives:** potassium
- **Lean meat and poultry, fish, eggs, tofu, nuts and seeds, legumes/beans:** niacin

Further, per 100 grams, or approximately five mushrooms (white button, raw), mushrooms provide more than 10% of the recommended daily intake (RDI) or the estimated safe and adequate daily dietary intake (ESADDI) [15, 16] of nine essential vitamins and minerals [14]:

- Niacin (38% of RDI),
- Biotin (28% of ESADDI),
- Vitamin B5 (24% of ESSADI),
- Selenium (23% of RDI),
- Vitamin D (21% of RDI),
- Copper (12% of ESSADI),
- Phosphorus (11% of RDI),
- Folate (11% of RDI),
- Potassium (>200 mg).

The comparison between the key nutrients in mushrooms and the key or 'distinguishing' nutrients in vegetables from the Australian Dietary Guidelines is shown in **Table 2**. Potassium and folate are the only characterising nutrients in common to both mushrooms and the vegetables food group. Mushrooms provide additional micronutrients not common in vegetables, including niacin, vitamin B5, biotin, vitamin D, copper, phosphorus, and selenium.

Table 2. Comparison of the key nutrients provided by mushrooms and vegetables (including legumes).

MUSHROOMS[1] (WHITE BUTTON, RAW)	VEGETABLES[2] (INCLUDING LEGUMES)
Niacin	Carbohydrate
Vitamin B5	Dietary fibre
Biotin	Pro-vitamin A
Folate	**Folate**
Vitamin D	Vitamin C
Copper	Iron
Phosphorus	Magnesium
Potassium	**Potassium**
Selenium	

Nutrients shared by both mushrooms and vegetables are shown in bold.

[1] At least 10% of daily requirement based on nutritional composition per 100 g [14-16].

[2] Characterising nutrients of the vegetables and legumes/beans core food group within the ADG [1].

Mushrooms have a unique nutritional composition.

Mushrooms (per 100 g) provide more than 10% of eight micronutrients to the diet. This includes niacin, vitamin B5, biotin, vitamin D, copper, phosphorus, and selenium, which are not common in vegetables. Thus, mushrooms make an important contribution to micronutrient shortfalls in the Australian population.

Mushrooms also provide unique bioactives not commonly present in vegetables

Mushrooms do not contain the characterising bioactives of the vegetables food group. These are the carotenoids [1], a family of red, orange, and yellow bioactive pigments. Research shows that these phytochemicals play important roles in health, including a reduced risk of type 2 diabetes, all-cause mortality, and some cancers [17]. While not considered to be characterising of the vegetables food group, additional bioactive compounds present in vegetables include (but are not limited to) flavonols in onions, asparagus, and broccoli, and anthocyanidins in cabbage and eggplant [18]. Vegetables can also be a significant source of dietary glutathione, with some vegetables containing similar levels to mushrooms, such as asparagus (28.3 mg/100 g), spinach (11.4 mg/100 g), and potatoes (11 mg/100 g) [19, 20].

The predominant bioactive compounds of mushrooms include ergothioneine, beta-glucan, chitin, glutathione, and phytosterols (particularly ergosterol):

Beta-glucans

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- **Definition:** Beta-glucans are polysaccharides, chains of sugar units with a structural role in the fungal cell wall [21].
- **Health effects:** Identified as having a range of beneficial health effects, including immunomodulatory, anti-inflammatory, anti-viral, and anti-cancer activity, as well as benefits for cardiometabolic (cholesterol-lowering activity) and digestive (prebiotic activity) health [22]. A recent systematic literature review (SLR) of randomised controlled trials (RCTs) on fungal beta-glucans found that the health-promoting properties are manifested primarily through the potentiation of the immune system [23].
- **Other dietary sources:** Also contained within cereals, although there are structural differences from the beta-glucans present in mushrooms [21].
- **Amount:** Varies by mushroom type, with the highest levels found in exotic varieties:
    - *A. bisporus* varieties contain 0.75 to 1.4 g/100 g fresh weight (FW) [24, 25].
    - Exotic varieties can contain up to 4.4 g/100 g FW (*P. eryngii*, or king oyster mushroom) [24].

Chitin

- **Definition:** A structural carbohydrate present in the mushroom cell wall [26, 27].
- **Health effects:** Health effects in humans include prebiotic and cholesterol-lowering effects. Additional benefits identified in rodent studies include metabolic, digestive, antiviral, antifungal, and anticancer activity [26].
- **Other dietary sources:** The only other food sources of chitin (in addition to other fungi) are crustaceans and insects [26].
- **Amount:** The chitin content of mushrooms ranges from 0.3 g/100 g FW in *P. ostreatus* mushrooms to 0.6 g/100 g FW in *A. bisporus* mushrooms [25].

Phytosterols (including ergosterol)

- **Definition:** Cholesterol-like substances found in plants, serving as structural components of biological membranes [28]. Also serve as precursors in the synthesis of other important bioactive compounds such as steroidal saponins and steroidal glycoalkaloids [28]. Mushrooms are notably high in the phytosterol ergosterol [13].
- **Health effects:** Identified health benefits include cholesterol-lowering and potential blood pressure lowering properties, as well as anti-cancer, anti-inflammatory, and anti-oxidation activities [28]. Ergosterol, on exposure to UV light, can be photosynthetically converted to ergocalciferol, or vitamin D_2 [13]. This is like the photochemical reaction that occurs in human skin, where 7-dehydrocholesterol is converted to cholecalciferol, or vitamin D3 [13].
- **Amount:** The composition of phytosterols is similar across both common and exotic mushroom varieties, ranging from 54.9 to 72.5 mg/100 g FW [24]. Mushrooms also contain notable levels of ergosterol (360 to 570 mg/100 g, depending on variety) [29].

Ergothioneine

- **Definition:** A sulfur-containing amino acid produced only by fungi and some cyanobacteria and mycobacteria [30]. Mushrooms contain the highest ergothioneine levels of any dietary source [30].
- **Health effects:** Potent antioxidant activity of importance for human health with a dedicated ergothioneine transporter present in many human tissues [30]. Also has anti-inflammatory and anticancer activity with possible additional roles in human development and reproductive health [31].
- **Other dietary sources:** Other sources include kidney, liver, and black beans [32].
- **Amount:** Levels of ergothioneine in mushrooms range from 1 to 26 mg/100 g FW [24, 30], with exotic varieties containing higher levels than *A. bisporus*.
    - *A. bisporus* mushrooms contain 1-4 mg/100 g FW ergothioneine, with the highest levels in white button mushrooms [24, 30].
    - Exotic varieties contain 5-26 mg/100 g FW, with the highest levels in enoki mushroom (*F. filiformis*) [24, 30].

Glutathione

- **Definition:** Peptide of 3 amino acids produced by the human body.
- **Health effects:** Known as the body's "master" antioxidant, the maintenance of optimal tissue levels of glutathione is critical for maintaining health and preventing diseases [30]. Low glutathione levels have been associated with increased risks for cancer, cardiovascular diseases, arthritis, and diabetes [30]. Dietary intake of glutathione may be important for the maintenance of optimal glutathione levels [30].
- **Other dietary sources:** Also present in some fruits and vegetables, including asparagus, green beans, spinach, and avocados, as well as mushrooms [19].
- **Amount:** Mushroom levels of glutathione range from 3.4 to 15.4 mg/100 g FW [30], with exotic varieties containing higher levels than *A. bisporus*.
    - *A. bisporus* mushrooms contain 3.4-6 mg/100 g FW glutathione, with the highest levels in white button mushrooms [30].
    - Exotic varieties contain 10.1-15.4 mg/100 g FW, with the highest levels in shittake mushroom (*L. edodes*) [30].

Other identified bioactives

- A range of additional bioactives are present in mushrooms, including flavonoids, phenolic acids, bioactive peptides, additional bioactive polysaccharides, and enzymes [33-41].
    - Emerging evidence has attributed several health-promoting activities to these additional bioactives, including antioxidant, anti-tumour, anti-hypertension, antifungal, immunomodulatory, antibacterial, antiviral, anti-inflammatory, and hypolipidemic activity [33-41].
    - In addition to vitamin D, exposure to sunlight has also been found increase levels of bioactives in mushrooms, particularly flavonoids, with corresponding increases in antioxidant activity [42].

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- Select mushroom species (including *A. bisporus* and *L. edodes*) contain lovastatin, a compound belonging to the statins group, commonly used as cholesterol-lowering drugs [43].
    - Research is emerging only and studies on the bioavailabilty and bioactivity of lovastatin from mushrooms are yet to be conducted.

Mushrooms have a unique bioactive profile.

Mushrooms contain a very different bioactive profile to vegetables, including ergothioneine, beta-glucan, chitin, and phytosterols (particularly ergosterol). These bioactives have important health effects, such as prebiotic and cholesterol-lowering properties, and may mean that mushrooms have different health effects to vegetables.

Mushrooms are a natural, vegan source of vitamin D, and the only non-fortified non-animal source in the diet

Unlike vegetables, mushrooms are a natural source of vitamin D (2.14 µg D_2/100 grams; 21% RDI). The vitamin D content in mushrooms can increase to more than 100% of vitamin D requirements when exposed to UV light (over 10 µg vitamin D_2/100 grams), such as from sunlight or UV lamps [13]. This large increase in vitamin D upon UV-light exposure is a result of their ergosterol content (a vitamin D_2 precursor which converts to vitamin D_2 in the presence of UV light) which is unique to fungi and dwarfs the vitamin D content of other vitamin D-rich foods including salmon (5.5 µg/100 grams) and eggs (5.9 µg/100 grams) [14].

The vitamin D content of UV-exposed mushrooms is generally >100-300% vitamin D needs, with the specific content dependent on the amount of UV-exposure, as well as surface area, mushroom type, light intensity, and length of exposure:

- The Australian Food Composition Database (AFCD) value for UV-exposed white button mushrooms is 24 µg/100 g fresh mushrooms (240% RDI), an increase of over 10-fold compared to non-UV exposed white button mushrooms [14]. These mushrooms were exposed to 1-2 seconds of UV light after harvesting.
- Fresh white button mushrooms exposed to midday sunlight for at least 15 minutes can generate over 10 µg vitamin D/100 g FW (>100% RDI), with sliced mushrooms producing higher levels compared to whole mushrooms due to the increased surface area [13].
- The vitamin D content of sliced mushrooms was 17.5 µg/100 g FW (175% RDI) after 15 min of midday and mid-summer sun exposure in Germany, and reached 32.5 µg/100 g FW (325% RDI) after 60 min of sun exposure [44].
- UVB radiation with a UV lamp has produced vitamin D_2 concentrations up to 320 µg/100 g FW (320% RDI) [13].

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What is the implication of mushrooms' unique nutritional composition?

Mushrooms can contribute high quantities of vitamin D, a nutrient which is absent in vegetables and is otherwise limited to animal-derived products or fortified foods. This is significant because a precedent has been set in the Australian Dietary Guidelines to recognise a subset of vegetables with unique nutrient compositions or 'distinguishing' nutrients [1], as is seen with the subcategory green and brassica vegetables that are rich in folic acid, and the subcategory orange vegetables, rich in pre-vitamin A. A new category for mushrooms, rich in vitamin D, is warranted.

Increasing mushroom consumption improves the intake of shortfall nutrients and reduces micronutrient deficiency

Two dietary modelling papers from the US and published in 2021 [45, 46] estimated the effect of adding one 84 gram serving of mushrooms on the nutrient composition of the diet. Increasing mushroom consumption had a beneficial impact on the intake of key nutrients and reduced levels of micronutrient inadequacy, with minimal impacts on energy, carbohydrate, fat, and sodium levels:

- Different diets were used as a baseline: usual intakes from the National Health and Nutrition Examination Survey (NHANES) 2011-2016 [46], and recommended US Department of Agriculture (USDA) Food Patterns, including the US-Style, Mediterranean, and vegetarian dietary patterns [45].
- The modelling investigated *A. bisporus* (a 1:1:1 ratio of white button, Swiss brown/cremini, and Portobello mushrooms) and *P. ostreatus* (oyster), or *A. bisporus* mushrooms (1:1:1 ratio) exposed to UV light to raise vitamin D levels to 5 µg/serving.
- A 84 g serve of *A. bisporus* mushrooms added to the baseline diet resulted in:
    - Increased dietary fibre, copper, potassium, selenium, riboflavin, and niacin in both usual intakes and recommended UDA Food Patterns.
    - Increased phosphorus, zinc, and choline in usual intakes for both adolescents and adults.
    - Increased iron, thiamine, folate, and vitamin B6 in usual intakes of adults.
    - A decrease in the % of the population with intakes below the EAR for copper, phosphorus, selenium, zinc, thiamine, riboflavin, niacin, folate, and vitamin B6 for adults over 19 years of age.
    - An increase in bioactives, including 2.2 mg ergothioneine and 3.5 mg glutathione.
- A 84 g serving per day of UV-exposed *A. bisporus* mushrooms added to the baseline diet resulted in:
    - A doubling of vitamin D intake and decrease in vitamin D inadequacy (from 94.9% to 63.6% in adults) compared to the usual US diet, and
    - Increased vitamin D intakes by 67 to 91% across recommended USDA Food Patterns.

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The nutritional composition of mushrooms used for this research was sourced from the USDA food composition database [24], where some differences exist to the AFCD, e.g. the vitamin D composition of *A. bisporus* mushrooms is lower in the USDA database (0.02 µg/100 g) compared to the equivalent composition provided in the Australian Food Composition Database [14].

What is the nutritional impact of adding mushrooms to the diet?

US dietary modelling has shown that one 84 gram serve of mushrooms per day can make notable contributions to the nutritional composition of the diet and reduce nutrient inadequacy for B-vitamins (folate , thiamine, niacin, vitamin B6), phosphorus, and the minerals copper, selenium, and zinc. UV-exposed mushrooms also had a meaningful impact on vitamin D intakes, increasing intake and decreasing inadequacy. Given vegetables have a different nutrient profile, they would not achieve these same outcomes.

The impact of cooking and storage on nutritional composition

The effects of culinary processes on nutrients and bioactives in mushrooms differ depending on the processing method and nutritional component and are summarised in **Table A5, Appendix 3.** Overall, vitamin D retention was highest with frying and bioactive levels were highest after microwaving or grilling.

Cooking:

- **Vitamin D:** Baking (70 to 200°C for 10 to 90 minutes) and boiling (10 to 30 minutes) decreased vitamin D levels up to 38% [13, 41, 47]. Frying had the least impact on vitamin D levels, with a 12% reduction after both low and high heat to 20 minutes [13, 41]. No data on vitamin D were reported for blanching, simmering, or grilling.
- **Beta-glucans:** Frying reduced beta-glucan levels by up to 58% [41], microwaving increased levels by 4% [47], and boiling and grilling showed mixed effects [41, 47].
- **Flavonoids and phenols:** Reduced up to 79% during blanching or simmering. The lowest losses occurred after grilling (8%) or microwaving (6%) [41, 47].
- **Antioxidant activity**: increased 31% during microwave cooking and decreased 10% during boiling [41, 47].

Drying:

- **Vitamin D:** While microwave drying reduced vitamin D levels up to 33%, hot air drying showed mixed effects, including both reduction (34%) and an increase of up to 9% [41]. There were no effects reported for freeze-drying and vitamin D, but freeze-drying showed mixed effects on levels of the vitamin D precursor ergosterol (no change or up to 15% decrease) [41].
- **Ergothioneine**: Levels were reduced up to 36% with hot air drying. Freeze-drying resulted in lower losses of up to 21% [41].

Storage:

- **Vitamin D:** There was little to no impact on vitamin D levels after refrigeration for 8 days, and a reduction of up to 25% after 14 days [13]. Storage of mushroom powder in dark dry conditions showed a 35% reduction in vitamin D levels after 8 months and a 52% reduction after 18 months [13].

Summary: Mushrooms have a unique nutritional profile and 'distinguishing' nutrients compared to vegetables

- Mushrooms provide a range of essential nutrients, including vitamin D, copper, niacin, phosphorus, biotin, vitamin B5, folate, selenium, and potassium. This nutrient profile is different from vegetables, where only folate and potassium are distinguishing nutrients in common as per the Australian Dietary Guidelines.

- Mushrooms contain a unique set of bioactives, including ergothioneine, beta-glucan, chitin and phytosterols, including ergosterol, not commonly found in vegetables.

- Mushrooms are the only natural and vegan (non-animal or fortified) source of dietary vitamin D and can provide more than 100-300% of vitamin D needs upon exposure to UV light.

- There is precedent in the Australian Dietary Guidelines that classify foods with a unique nutrient compositions or 'distinguishing' nutrients together, yet the current guidelines do not recognise the unique nutritional composition of mushrooms.

- Dietary modelling has shown that adding mushrooms (84 g/day) to the American diet can make a significant contribution to the intake of key nutrients and could reduce the levels of micronutrient inadequacy for copper, phosphorus, selenium, zinc, thiamine, riboflavin, niacin, and vitamin B6, and vitamin D when UV exposed. Vegetables would not achieve this as they do not have the same nutritional composition.

Q3: What is the significance of mushrooms being a source of vitamin D?

Vitamin D deficiency is defined as serum 25-hydroxyvitamin D concentrations [25(OH)D] < 50 nmol/L) [48, 49] and vitamin D insufficiency has been defined as serum [25(OH)D] 50-75 nmol/L [48, 49]. Rates of vitamin D deficiency and insufficiency are high both in Australia and globally:

- **Australia:** an average of 20% of people are vitamin D deficient:
  - 4% of pre-school children [50],
  - 17% of adolescents and 32% of young adults [51],
  - 20% of adults [52],
  - 16 to 20% of adults aged 65 years and over [53],
  - 27% of Australian Aboriginal and Torres Strait Islander adults [54], and
  - A further 43% of adults [52] and 16% of pre-school children [50] were vitamin D insufficient.
- **Globally:** in a recent SLR and meta-analysis (MA) involving 7.9 million participants globally, almost 1 in 2 (47.9%) were vitamin D deficient [55].
  - There was a higher prevalence of vitamin D deficiency during winter to spring (1.7 times higher than summer to autumn), in females, in people living in high latitude areas, and in those from the Eastern Mediterranean region and lower-middle-income countries.
  - Additional SLR evidence globally has shown vitamin D deficiency levels up to 94% in nursing homes [56] and up to 27% in pregnant women [57].
  - An additional 28.7% of people globally are vitamin D insufficient [55].

Vitamin D deficiency and insufficiency are considered significant public health issues with an increased risk for both infectious and non-communicable diseases:

- Vitamin D deficiency is well established to decrease calcium absorption and result in impaired bone health [58].
- Studies have linked vitamin D deficiency or insufficiency to increased susceptibility to infectious diseases (including COVID-19 and upper respiratory tract infection), as well as muscle weakness, multiple sclerosis, diabetes, hypertension, metabolic syndrome, cancers, autoimmune diseases, cardiovascular disease, and hip or vertebrae fracture in later life [55].
- Vitamin D deficiency during pregnancy has also been associated with an increased risk for gestational diabetes [59].
- While sunlight is considered to be a primary source of vitamin D [6, 49], these data suggest that the majority of individuals (including Australians) do not produce sufficient vitamin D via this source, whether due to limited sun exposure due to working indoors, having dark skin, or specifically avoiding sunlight due to sensitivity.

Vitamin D intakes are well below recommended levels

A key factor contributing to Vitamin D deficiency could be low dietary intakes. These are well below dietary recommendations:

- More than 95% of Australians have vitamin D intakes lower than recommended.
    - In a 2023 evaluation of the 2011-2013 Australian Health Survey, average intakes ranged from 1.84 to 3.25 µg/day for people 2 years old or more [49]. More than 95% had intakes <10 µg/day and no participant exceeded the Upper Level of Intake (63-100 µg/day).
    - The adequate intake (AI) for vitamin D in Australia is 5 µg/day for children and adults up to 50 years of age, 10 µg/day for adults 51-70 years, and 15 µg/day for adults over 70 years [60].
- The Institute of Medicine in the US recommends an EAR for vitamin D of 10 µg/day [61].
    - Global adult intakes are between 3.5 and 6 µg/day in the US, 5.8 µg/day on average in Canada, 2 to 4 µg/day in Europe, and up to 3.7 µg/day in Ireland [13].

While low vitamin D intakes is common across all adult age groups, the elderly, pregnant women, and people from low to middle socioeconomic areas have been highlighted as particularly vulnerable, often with increased vitamin D needs [55-57]. Vegetarians and vegans may also have increased difficulty obtaining sufficient vitamin D due to their restricted intake of animal foods [13].

Vitamin D is a pressing health problem in Australia

Vitamin D deficiency is a significant global public health problem, and Australia has some of the lowest estimated intakes of vitamin D globally.

There is no clear solution to the vitamin D problem

Diets produced during modelling to inform the ADG, underpinned by a balanced intake of each of the core food groups, are inadequate for vitamin D [6]. This is the same for the modelling conducted to inform the more recent US Dietary Guidelines [62]. Vitamin D was also the **only** nutrient that could not consistently be met in the modelling to inform the ADG [6]. This indicates that meeting vitamin D needs is particularly difficult and that current eating patterns require additional support to do so.

Recent dietary modelling in Australia [63] showed that the fortification of milk with vitamin D (0.8 µg/100 mL milk; the maximum permitted level) would increase vitamin D intake to 4.9 µg/day. This is a meaningful increase but still below dietary targets. Previous Australian dietary modelling conducted in 2013 [64] estimated that if all milk and breakfast cereals were to be fortified with vitamin D (1 µg/100 mL in milk, and 3.5 µg/100 g in breakfast cereals), the average intake of vitamin D from foods would increase to 6.3 µg/day. This increase would allow vitamin D intakes to be met for adults up to 50 years of age [60], although this level of fortification for milk is more than the amount currently permitted in Australia [64, 65] and breakfast cereals that do not meet the Nutrient Profiling Scoring Criteria are currently not permitted to be fortified with vitamin D [66].

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In modelling to inform the US Dietary Guidelines, several hypothetical models were explored to meet vitamin D needs [62]. The only option that brought vitamin D intake to the recommended level encouraged seafood choices with the highest quantities of vitamin D, fortification of both dairy and juice, and the potential fortification of grain products, but even in this model, it was unrealistic as seafood choices were limited to those not normally consumed.

Mushrooms have significant potential in addressing vitamin D deficiency

Mushrooms are a natural source of vitamin D and may be an important part of a solution towards addressing the vitamin D public health issue:

- Raw white button mushrooms naturally contain 2.14 µg vitamin D3 equivalents per 100 g, equivalent to 21% of the RDI per 100 g [14]. This is without UV or sunlight exposure.
- UV-exposed white button mushrooms contain 24 µg/100 g [14], providing over 100% of vitamin D needs for all Australians.
- A 2023 systematic literature review identified that vitamin D dosages of 15 to 95 µg/day from UV-exposed mushrooms increased serum levels of vitamin D2 [67]. UV-exposed mushrooms providing 50 µg vitamin D/day have also been shown to be equivalent to a supplement at increasing serum vitamin D levels [3].
- As the only natural, non-animal source of vitamin D in the diet, mushrooms have a particularly critical role in helping vegetarians and vegans to increase vitamin D intake.
- Both forms of vitamin D (D_2 and D_3) are considered beneficial for health [68].

Summary: Mushrooms have a potential role to address vitamin D deficiency.

- Vitamin D deficiency is a global public health issue and an average of 63% of Australians are deficient (20%) or insufficient (43%).
- Australia has one of the lowest intakes of vitamin D globally, with more than 95% reporting intakes <10 µg/100 g.
- Vitamin D is the most difficult nutrient to meet in dietary modelling for dietary guidelines, and there is no clear solution to meeting vitamin D needs.
- Mushrooms are a natural and vegan source of vitamin D (non-animal and non-fortified) and, when exposed to UV, can provide over 100% vitamin D needs, having a similar efficacy to vitamin D supplements for increasing vitamin D status.
- Vitamin D_2 (fungi) and vitamin D_3 (animal) are are considered to be equally beneficial for health..
- These findings have important implications for all Australians, and particularly for the elderly, pregnant women, and vegetarians and vegans.

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Q4: What are the key culinary properties of mushrooms and how do these differ from vegetables?

Recent recommendations are to increase consumption of plant foods, such as vegetables, and reduce the intake of meat, particularly red meat, and highly processed foods, for both health and environmental sustainability [69]. Taste and texture have been identified as barriers to increased intake for vegetables [70] and meat alternatives [71], yet mushrooms possess culinary properties (including taste and texture) that are unique from both vegetables and plant-based meat alternatives. These properties allow them to be substituted, at least in part, for meat in the diet, and achieve improvements in overall dietary quality, such as reduced salt and saturated fat intake, in ways that vegetables are unlikely to replicate.

The culinary properties of mushrooms

The predominant culinary properties that distinguish mushrooms are their umami flavour and texture/mouth-feel.

Umami flavour

The umami taste and aroma are the most prominent culinary features of mushrooms. The savoury umami flavour is produced by a combination of the naturally present amino acids glutamate and aspartate and 5'-nucleotides (such as 5'-inosinemonophosphate), as well as volatile compounds and other components [2, 72]. The umami composition (as glutamate and 5'-nucleotides) of mushrooms compared to other umami foods is presented in **Table 3**. In addition to umami flavour, mushrooms also have low sodium content, compared to many other umami-rich foods.

Table 3. Umami and sodium content[1] of umami-rich foods

FOOD	GLUTAMATE (mg/100g)	SODIUM (mg/100g)
Common mushrooms	40 – 100	9
Fresh shiitake mushrooms	70	9
Potatoes, raw	30 – 100	6
Sweet potatoes, raw	60	55
Tomatoes, red/ripe	150 – 250	5
Carrots, raw	40 – 80	69
Parmesan cheese, dry grated	180	1529
Soy sauce	400 – 1700	5493
Beef ground, 80% lean	10	66
Pork tenderloin, raw	10	53
Chicken ground, raw	20 – 50	60

[1] Umami and sodium content based on previously presented data [2, 73].
mg, milligrams

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Their umami flavour is enhanced via high heat (such as in oven roasting) due to the Maillard reaction; this chemical reaction between amino acids and sugars with heat leads to caramelisation and its accompanying flavour [72]. Umami compounds in mushrooms also interact with those in other umami-rich ingredients (such as tomatoes) to have a synergistic effect on flavour, increasing both depth and length of taste [2].

Analysis of the umami flavour in a range of mushroom samples, measured by both human sensory evaluation and high performance liquid chromatography (HPLC), showed the highest levels of umami flavour intensity for *A. bisporus* and *P. ostreatus* mushrooms [74].

Texture

Mushrooms have a high moisture content and contain chitin, which contribute to a meaty texture and mouth-feel [2]. This enables mushrooms to be substituted for meat in vegetarian dishes or meals while maintaining a similar mouthfeel and palatability [2].

Umami flavour for sodium reduction

There is a positive association between sodium intake and increased blood pressure, yet sodium intake far exceeds recommendations globally [75]. The replacement of sodium with umami flavour in foods has been suggested as one method to reduce sodium consumption while maintaining flavour and acceptance. A 2022 scoping review including 52 studies (interventional and observational research) identified a beneficial effect of the addition of umami flavour for sodium reduction in foods whilst maintaining acceptance [75]; umami flavour was predominantly added via monosodium glutamate, but also included foods such as tomato, mushrooms, and yeast.

While umami flavour is provided by a range of different foods, the sodium content of these foods differ; the use of umami for sodium reduction requires the selection of foods both providing umami flavour and a low sodium content (**Table 3**).

The unique culinary properties of mushrooms as a meat alternative

The reduction of diet-related disease and efforts to increase environmental sustainability have been highlighted as critical areas of focus for public and planetary health; recommendations include (but are not limited to) increased plant-based foods and decreased animal foods, saturated fat, added sugars, and highly processed foods [69]. While consumer demand for plant-based meat alternatives has increased both globally [76] and in Australia [77], many products are highly processed, can be high in saturated fat, and may not provide the nutritional benefits as their whole food from which they were derived [76, 77]. A recent cross-sectional study identified that while meat alternatives in Australia had a higher health star rating (by 1.2 stars), lower mean saturated fat (by 2.4 g/100 g), and lower sodium content (by 132 mg/100 g), compared to traditional meat products, the total sugar content was higher (by 0.7 g/100 g), and 84% of meat alternatives were ultra-processed when classified according to the NOVA system [77].

Meat also has unique sensory properties, such as texture and flavour, which have been identified as key barriers to dietary meat reduction [76]. Thus, in addition to the identified increased demand for plant-based meat analogues able to mimic the structure, texture, taste and appearance of traditional meat products [76], there is a public health need for unprocessed meat analogues that can overcome barriers to meat reduction.

Mushrooms are a whole, unprocessed food that possess the unique culinary properties of a meaty texture and savoury umami flavour; mushrooms therefore serve as an unprocessed meat analogue and can assist in overcoming the barriers to decreased meat consumption.

The nutrition implications of the unique culinary properties of mushrooms

Five experimental studies were identified that analysed the sensory impact of the substitution of meat with mushrooms (**Table 4**). There was consistent evidence for acceptable sensory appeal with up to 80% substitution, and evidence for increased flavour when fresh mushrooms were substituted for red meat, even when salt levels were reduced.

In these studies, the replacement of meat for mushrooms was accompanied by a decrease in total energy, protein, saturated fat, and sodium intakes, and increased fibre and potassium intakes. These changes in dietary composition are significant given that current intakes of saturated fat and sodium are higher than recommended levels [1]. While protein intake was also reduced, protein is not lacking in the Australian population [78]. Mushrooms also have a much lower potential environmental impact (measured by carbon footprint) in comparison to meat, indicating that the substitution of meat for mushrooms holds weight both nutritionally and environmentally [79].

- In two studies, the substitution of red meat for mushrooms in a taco filling were preferred by participants, even when salt levels were reduced [80, 81].
    - In a 2014 proof-of-concept study [80], *A. bisporus* mushrooms were shown to enable sodium reduction without reducing flavour when used as a substitute for meat (at up to 80%) in meat-based dishes. Detailed subjective sensory analysis showed:
        - No effect on overall flavour strength when substituted either within a ground beef taco filling or carne asada (spiced grilled meat).
        - Overall flavour was enhanced, with mushroom, veggie, onion, garlic, and earthy flavours increased, and both umami and sweet tastes detected.
        - When sodium was reduced by 25% the flavour intensity of the 80% mushroom taco blend matched that of the full-salt 50% mushroom blend, as well as the all-meat control.
    - In 2017 study, Wong *et al* investigated the integration of *A. bisporus* mushrooms (white button and Portobello) into a beef taco filling to reduce levels of sodium for food service applications [81].
        - Consumers preferred a 45% mushroom taco filling with reduced sodium (by 45%), compared to its full sodium counterpart in a food service sensory test.
        - The mushroom mixture was equivalent in physical attributes (including moisture, colour, and texture) to the all-meat control, and had lower saturated fat.

- In a 2019 study [82], mushrooms out-performed textured soy protein (TSP) in substituting for meat and lowering sodium content in beef patties.
    - Mushrooms were closer to the all-meat control in liking scores compared to the TSP.
    - Both the mushroom and TSP had similar physical properties compared to the all-meat control, although water retention was decreased with mushrooms.
    - A 50% substitution of meat for mushrooms reduced sodium and total fat content in the beef patties by approximately 20% and 25%, respectively.
- In a 2021 study [83], mushrooms were comparable to chicken in sensory characteristics when substituted up to 80%, although these were higher in salt and there was a decrease in flavour of the all-chicken patties when their salt levels were reduced by 25%.
    - No significant changes in physical properties, except colour, between full-chicken and chicken-mushroom nuggets.
    - Reduction of salt by 25% in the all-meat chicken patties decreased their liking scores.
- In a 2020 study [84], adding *A. bisporus* and *P. ostreatus* flour to frankfurter sausages reduced both salt and fat levels by 2.5% and 5%, respectively.
    - Addition of mushrooms flour increased moisture and dietary fibre content, without significantly affecting overall amino acid profile.
    - Although lower colour, flavour, and taste scores were given to the mushroom samples than the control, they still ranked within an acceptable level.

Why are the culinary properties of mushrooms important?

Saturated fat and sodium are nutrients of concern that are consumed by the Australian population. Mushrooms have unique culinary properties compared to vegetables (including umami flavour and meaty texture) that allows them to be substituted up to 80% for meat in dishes without compromising taste, texture, likeability, and palatability. This substitution is a practical pathway to improving dietary quality, including reducing saturated fat and sodium intakes and increasing fibre and potassium intakes, overcoming barriers to meat reduction, with a lower environmental impact. Vegetables, where taste is a common barrier to consumption, are unlikely to have the same impact.

Mushroom powder or flour has also been added to a range of foods experimentally to increase diet quality [42, 85-90]. While results consistently show good sensory acceptance and improved nutritional composition, low to moderate levels of inclusion had better sensory acceptance than the highest levels of inclusion:

- Foods tested included semolina pasta, gluten free dough and biscuits, vegetable soup, wheat bread, cereal bars, porridge, waffles, breadsticks, and salad cream.
- Mushroom types used were predominantly *A. bisporus* and *P. ostreatus.*
- Nutritional effects included increases in protein, fibre, calcium, zinc, potassium, and bioactives including beta-glucans and polyphenols.

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Table 4. The effect of including fresh mushrooms or mushroom flour as a meat replacement or nutritional supplement on nutritional profile and sensory scores.

FOOD	MUSHROOM TYPE	NUTRITION AND BIOACTIVES	SENSORY ANALYSIS
Meat replacement			
Taco filling [80, 81]	*A. bisporus*	↓ sodium, saturated fat	Equivalent to all-meat control, even with reduced salt.
Beef patties [82]	*A. bisporus*	↓ sodium, fat	Equivalent to all-meat control and better liked than substitution using TSP.
Chicken nuggets [83]	*A. bisporus*	↓ sodium, fat, protein; ↑ carbohydrate, fibre	Comparable to all-meat control but decreased flavour with sodium reduction.
Frankfurters [84]	*A. bisporus* and *P. ostreatus* (flour)	↓ sodium, fat; ↑ dietary fibre; ↔ amino acid profile	Acceptable, though lower colour, flavour, and taste vs control.
Other foods			
Semolina pasta [90]	Lion's Mane, Reishi, Enoki, and Maitake	↑ protein, fibre	Acceptable; low to moderate levels of inclusion preferable.
Gluten free dough and biscuits [89]	*A. bisporus*	↑ protein, fibre, amino acids, minerals	Acceptable; lower levels of inclusion better.
Vegetable soup [85]	*P. ostreatus*	↑ beta-glucan	Comparable liking to control; lower levels of inclusion preferable.
Wheat bread [87]	UV-exposed *A.bisporus*	↑ vitamin D, total polyphenols	Positive effect on a hedonic (liking) scale.
Cereal bars [88]	*L. edodes*	↑ calcium, iron, phosphorus, potassium, zinc, manganese, phenolic compounds, glucans	Acceptable; better sensory analysis for sweet vs salty bar.
Porridge [86]	*P.ostreatus*	↑ protein, fibre, iron, zinc, calcium, potassium	Good acceptance of flavour, colour, and aroma
Waffles, breadsticks, and salad cream [42]	UV-exposed *P.ostreatus*	↑ protein, fat, vitamin D, bioactives, antioxidant activity (all foods tested); ↓ carbohydrate (waffles, breadsticks)	Equivalent sensory evaluation vs control.

↑, increase; ↓, decrease; ↔, no change

Cost impact of substituting meat for mushrooms

The replacement of meat for mushrooms can also result in cost savings. Based on the lowest costs identified for trimmed red meat ($1.60 per 100 g) and white button mushrooms ($1.27 per 100 g) at the major Australian supermarkets of Coles and Woolworths in April 2023:

- Substitution of 50% red meat for mushrooms (weight for weight) produced a savings of 11%.

- Substitution of 75% red meat for mushrooms (weight for weight) produced a savings of 28%.

Summary: Mushrooms have unique culinary properties

- Taste is a common barrier to vegetable consumption, but mushrooms have unique culinary properties from vegetables, that includes a umami flavour and meat-like texture.
- The substitution of meat for mushrooms shows comparable or increased liking scores in sensory analysis, and improved nutrient intakes, including a reduction in calories, saturated fat, and sodium, and increases in fibre and potassium.
- The substitution of red meat with mushrooms also results in costs savings.
- This means that mushrooms may be a practical and cost-effective strategy to improving dietary quality and lowering environmental impact, that is unique from vegetables.

Q5: What are the unique health effects associated with mushroom consumption and how do these differ from vegetables?

Mushroom consumption has been associated with a range of positive health outcomes, including beneficial effects on cardiometabolic markers, cancer risk, and gut microbiota composition. UV-exposed mushrooms have also been shown to have a significant impact on vitamin D status. While the inclusion of vegetables within the diet is also associated with a wide range of health outcomes largely like those observed with mushroom consumption and supported by a far greater quantity of high-quality evidence, the improvement in vitamin D status, and possible a reduced risk of ovarian cancer, is unique to mushrooms.

- A total of 16 studies investigating the relationship between mushroom consumption and health were identified, across eleven different health outcomes (**Table A6, Appendix 4**).
- The predominant species studied was *A. bisporus* (common mushroom), followed by *P. ostreatus* (oyster mushroom) and *L. edodes* (shiitake mushroom).

Improved vitamin D status

Four papers addressing the relationship between mushroom intake and vitamin D status were identified, including a scoping review [3], one SLR of six clinical trials [67], and two RCTs [91, 92]. UV-treated mushrooms, predominantly *A. bisporus*, were effective at increasing blood levels of vitamin D2 (25-hydroxy D2, or 25(OH)D2).

Mushrooms providing 600 IU/day (15 µg/day) of vitamin D were sufficient to significantly increase serum 25(OH)D2 levels, and UVB-exposed mushrooms at doses of 2000 IU/day (50 µg/day) were equivalent at increasing total 25(OH)D2 levels to a vitamin D supplement.

Inflammation and immune function

Two papers addressing inflammation and immune function were sourced, including a scoping review on *A. bisporus* [3] and one RCT [93] investigating *L. edodes* extract. There were mixed effects on immune and inflammatory markers that depended on the marker, mushroom species, form (fresh vs powder/extract), and dose:

- 100 g/day fresh *A. bisporus* increased secretory immunoglobulin A (sIgA) levels, indicating a potential benefit for mucosal immunity [3].
- 8 to 16 g/day powdered *A. bisporus* decreased levels of the inflammatory cytokine TNF-α [3], and a 10.4 g dose of *L. edodes* had no effect on TNF-α levels [93].
- Powdered *A. bisporus* increased levels of the antioxidant ergothioneine and the oxygen radical absorbance capacity (ORAC), a measure of antioxidant capacity [3].
- No effects of any mushroom on other markers of inflammation or immunomodulation, including IL-1β, IL-2, IL-4, IL-6, IL-10, IL-12, IL-13, IL-17, interferon-γ, serum creatinine, or oxidised LDL cholesterol.

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Appetite and energy intake

Two papers investigating appetite or energy intake were identified, the scoping review on fresh *A. bisporus* [3] and one RCT on oven-dried *P. ostreatus* [94]. There was a consistent effect on subjective hunger and mixed findings for other subjective appetite-related markers and energy intake:

- 226 g/day fresh *A. bisporus* significantly reduced feelings of hunger, prospective food consumption (a subjective measure of the amount a person thinks they can eat), and increased feelings of fullness, when compared to isoenergetic quantities of beef [3]. It also had mixed effects on energy intake; having no effect when substituted for beef matched for kJ but decreasing energy intake when substituted for beef matched for volume (and thus the meat provided higher kJ) [3].
- A 20 g dose of powdered *P. ostreatus* added to a meal significantly reduced feelings of hunger and had no effect on feelings of fullness, desire to eat, or the appetite-related peptides ghrelin and gastric inhibitory peptide (GIP) vs. a control meal [94].

Cancer

A recent SLR and MA of 17 observational studies [95] reported on the relationship between mushroom consumption (primarily *A. bisporus*) and cancer, with a consistent protective effect shown for mushroom consumption. Most studies included in the reviews were observational (cohort and case-control), with one Phase 1 clinical trial also identified in the scoping review [3].

- Higher mushroom consumption decreased risk for ovarian cancer (by 32%), total cancer (by 34%), and breast cancer (by 35%) vs lower mushroom consumption [3, 95].
- Total cancer risk was decreased by 45% at a mushroom intake of 18 grams/day [95].
- In a Phase 1 clinical trial, levels of the prostate specific antigen (PSA) decreased with a higher (4–14 g extract daily; equivalent to 40–140 g fresh mushrooms) vs. lower intake of mushrooms [3], indicating lower levels of prostrate growth.
- The potential biological mechanisms underlying the association between mushroom consumption and lower risk of cancer were suggested to stem from mushroom specific bioactives [95]:
    - Antioxidants ergothioneine and glutathione, with oxidative damage known to play a role in cancer pathology.
    - Polysaccharides such as beta-glucans, that have been implicated as having antitumor and immunomodulation properties.

Gastrointestinal (including gut microbiota)

Studies investigating the impact of mushrooms on gastrointestinal health included a 2020 scoping review [3] and one RCT [93]. Both *A. bisporus* and *L. edodes* mushrooms featured, with consistent beneficial effects on digestive function and gut microbiota composition.

- *A. bisporus* mushrooms lead to an increased ratio of Bacteroidetes to Firmicutes in comparison to red meat [3], associated with improved metabolic health [96].

- *L. edodes* mushroom extract modulated the gut microbiota differently compared to placebo, including a correlation between increased levels of the family *Ruminococcaceae* and the genus *Bifidobacterium* [93].
- Consumption of fresh and extracted *A. bisporus* also had beneficial effects on stool weight (increase), bowel strain (decrease), and faecal odour and halitosis (decrease) [3]. There was no effect on bowel regularity or the production of short chain fatty acids [3].
- Doses of *A. bisporus* were 50 to 1000 mg/day extract or 226 g/day fresh mushrooms; the dose of *L. edodes* was 10.4 g/day extract.

Markers of cardiometabolic health

Eight studies reported on mushroom consumption and markers of cardiovascular or metabolic health. These included a 2020 scoping review [3], three SLRs [97-99], and four RCTs [93, 94, 100, 101]. The effect of mushrooms beneficial, although there were mixed effects for some markers and mushroom varieties.

- *A. bisporus* (fresh):
    - A dose of 2 g/kg body weight/day (150 grams for a 75 kg person) was associated with significantly lower glucose, total cholesterol, low-density lipoprotein, triglycerides and body weight, and higher high-density lipoprotein, compared to control [3].
    - Doses of around 100 g/day reduced blood triglyceride levels and blood pressure and had potential benefits for blood glucose in intervention studies, with no effect on total or LDL-cholesterol [99].
    - In adults with metabolic syndrome, 100 g/day increased adiponectin, a hormone with a role in the maintenance of healthy glucose levels, lipid metabolism, and insulin sensitivity [102].
    - In a year-long RCT, where participants consumed 226 g mushrooms in place of meat for 3 meals/week, there was beneficial effects on cardiometabolic markers including reduced bodyweight (by 7 pounds), BMI (by 1.53 kg/m2), waist circumference (by 2.6 inches), percent body fat (by 0.85%), systolic and diastolic blood pressure (by 7.9 and 2.5 mmHg, respectively), and the inflammatory marker CRP (by 1.15 mg/L).
- *P. ostreatus*:
    - Inconsistent effects on glucose metabolism (reduction or no change in fasting or 2 h postprandial glucose), lipids (decrease or no change in total cholesterol, LDL-cholesterol and/or triglycerides) [94, 97, 98, 100], and blood pressure (increase, no change, or decrease) [97].
- *L. edodes*:
    - Inconsistent effects on triglycerides (decrease or no change) [99, 101] at doses from 3.5 to 10 g/day powdered mushroom.

Cardiometabolic disease

Two SLRs [98, 99] investigated the association between mushroom consumption and risk of cardiometabolic disease, including cardiovascular disease (CVD), coronary heart disease (CHD), stroke, and type 2 diabetes mellitus (T2DM). There was no effect on the risk of any cardiometabolic disease.

- Mushroom types included *A.bisporus*, *P. ostreatus*, and *L. edodes*, as well as *Ganoderma lucidum* (reishi) mushroom, *P. cystidiousus* (abalone mushroom), and not specified.
- Doses included 3.5 to 15 g/day powder, 100 to 260 g/day fresh, 5 servings per week, or higher vs lower intake.

Cognitive function

Two studies reporting on the association between mushroom consumption and cognitive function were identified, one RCT [92] and one cross-sectional study [103]. There were mixed findings, depending on the cognitive test used and type of research.

- In the RCT [92] there was no significant effect of either a standard or a UV-treated mushroom (*A. bisporus*) extract providing an equivalent dose of 600 IU vitamin D/day (15 µg/day) on scores for a range of cognitive abilities, including reaction time, recognition memory, and overall quality of memory among others.
- In cross-sectional research [103], higher levels of mushroom consumption (a median intake of 13.4 g /1000 kcal/day) were associated with higher scores on 2 out of 4 cognitive function tests, the Alzheimer's Disease Word Learning (CERAD-WL) (which assesses new verbal learning) and the Digit Symbol Substitution Test (DSST) (which evaluates attention and processing speed). There was no association between mushroom consumption and measures of memory or semantic fluency.

Mood

One RCT [92] and one cohort study [104] assessed the relationship between mushroom consumption and measures of mood. Findings were mixed, depending on the study type and test used.

- In the RCT [92] there was no significant effect of either a standard or a UV-treated mushroom (*A. bisporus*) extract providing an equivalent dose of 600 IU vitamin D/day (15 µg/day) on mood and depressive symptoms.
- In contrast, higher mushroom consumption was associated with reduced depressive symptoms, assessed by the Center for Epidemiological Studies-Depression (CES-D) score, in a cohort of over 87,000 Korean adults over a period of 5 years [104]. The association was more prominent for women and people aged over 40 years.

Mortality

The impact of mushroom consumption on risk of mortality was addressed in one SLR [99] and one MA of five prospective cohort studies [105], with a beneficial association observed for all-cause mortality. Mushroom varieties included *A. bisporus*, *P. ostreatus*, and *L. edodes*, among others.

- There was a 6% decreased risk of all-cause mortality with a higher vs lower consumption of mushrooms in the MA of prospective cohort studies [105].

- There was no association between any level of mushroom consumption (fresh or powdered) and CVD-associated mortality in a SLR of 22 studies, which included both RCTs and observational research [99].
- In a prospective cohort study from the US, using data from the Third National Health and Nutrition Examination Survey, consuming mushrooms instead of red or processed meats was associated with 35% lower risk of all-cause mortality [106].

Summary: Mushrooms may have some unique health outcomes vs. vegetables

- Similar to vegetables, mushroom consumption is associated with a wide range of health effects, including:
    - Improved markers of mucosal immunity;
    - Decreased risks of cancer and all-cause mortality;
    - Improved gut microbiota composition;
    - Improved cardiometabolic markers.
- Unlike vegetables, mushrooms improve vitamin D status (when UV-exposed) and are associated with reduced ovarian cancer risk. These unique effects may be explained by their bioactive profile that is unique to fungi.
- The substitution of meat for mushrooms in the diet can produce beneficial effects on cardiometabolic markers, subjective appetite, gut microbiota composition, and the risk of all-cause mortality.
- Doses associated with health outcomes are 100 to 260 g/day fresh mushrooms, and 10 to 20 g mushroom extract.

Q6: What is the effect on nutritional intake if mushrooms were to become their own subcategory within the vegetable food group?

Revamping the current sub-categories of the 'vegetables and legumes/beans' food group to include mushrooms has the potential to improve micronutrient intakes, but dietary modelling is required to validate this.

The results of this modelling are summarised below. Detailed tables showing the nutritional composition of each diet with 0, 3, and 7 serves of mushrooms per week are provided in **Appendix 5, Tables A7** to **A12.** The specific results for vitamin D are presented in **Table 5** for mushrooms (*A. bisporus* white button) and **Table 6** for UV-exposed mushrooms (*A. bisporus* white button).

- **Mushrooms:** Vitamin D intakes were increased but generally still below the AI, except for women 19-30 years consuming 7 serves of mushrooms per week as part of an omnivore diet.
- **UV-exposed mushrooms:** Vitamin D needs were met for all demographic groups with an intake of between just 1 to 4 serves of UV-exposed mushrooms per week.

Why vitamin D is an important nutrient to address in dietary modelling

The 2013 ADG was informed by dietary modelling [6]. This is to help ensure that food group recommendations met nutrient requirements.

The *Foundation Diets* include only foods from the Five Food Groups and allow for unsaturated spreads and oils. They are designed to provide all the nutrient needs of a particular age, gender, or life stage within the energy needs of the smallest and most inactive members of that group. A range of models including omnivore (all foods) and lacto-ovo vegetarian (vegetarian including eggs and dairy) dietary patterns were developed.

Foundation Diets can be built upon to develop a *Total Diet* for an individual, which reflects the additional energy requirements related to the individuals body size and activity levels, while allowing some flexibility for personal food preferences.

In the modelling for both *Foundation Diets* and *Total Diets*, vitamin D was consistently low for all demographic groups. This means that the current ADG are insufficient for helping people to meet their vitamin D needs through diet alone, and that changes to the current guidelines may be required to better help address this.

Modelling mushrooms as a sub-category of vegetables

Modelling was undertaken for both an omnivore diet and ovo-lacto vegetarian diet:

Omnivore diet

The addition of a new sub-category of vegetables containing *A. bisporus* (white button) mushrooms to Omnivore Foundation diets increased vitamin D intake for all demographic groups analysed (**Table 5**). The diets also still met the NRVs for all other nutrients (**Appendix 5**):

Effect on vitamin D

- The substitution of 7 serves of "other vegetables" for 7 serves of white button mushrooms per week increased vitamin D intakes for women aged 19-30 years by 55% to 5.1 µg/day, 101% of the AI.
- The substitution of 7 serves of "other vegetables" for 7 serves of white button mushrooms per week increased vitamin D intakes for men aged 51-70 years and women aged 70+ years, from 4.6 to 6.5 µg /day, a 41% increase. Neither group met the AI for vitamin D, reaching 65% and 43% of the AI, respectively.
- Substitution of 3 serves per week increased vitamin D intakes by 15-18% across demographic groups. No group was able to meet the vitamin D AI at this level of consumption.
- Dietary modelling was also used to determine the number of serves of mushrooms per week that would allow men aged 51 to 70 years and women aged 70+ years to meet their AI for vitamin D. For men aged 51 to 70 years, 19 serves of mushrooms per week were required, and 36 serves per week were needed for women aged 70 plus years, equivalent to 204 g/day and 386 g/day, respectively. This quantity of mushrooms may not be feasible in the normal diet.

Other nutrients

There were decreases in the provision of some nutrients compared to the original *Foundation Diets*, such as riboflavin, folate, vitamin C, and zinc, but these decreases were small, and diets still met the NRV for all nutrients and for all demographic groups. There was also a small increase in the provision of iron for women aged 19-30 years and magnesium for men aged 51-70 years, providing another benefit over the original *Foundation Diets*.

Substitution vs. addition

Similar results were obtained whether mushrooms were incorporated via substitution (serves added in place of "other vegetables" serves) or addition (serves added on top of other vegetables serves), for all demographic groups. Even with the addition of 7 serves of mushrooms on top of the existing 14 serves of other vegetables used within the original *Foundation Diets*, energy intake was minimally affected (1% increase).

Ovo-lacto Vegetarian diet

Effect on vitamin D

Dietary modelling again showed increases in vitamin D intakes when mushrooms were either substituted for "other vegetables" or added to the diet on top of the existing "other vegetables" serves:

- An 86 to 120% increase in vitamin D intakes across the demographic groups, and an approximate doubling in the ability of all groups to meet their NRV for vitamin D.

Since the original Ovo-Lacto Vegetarian *Foundation Diets* contained less vitamin D than the original Omnivore *Foundation Diets*, even with the addition of 7 serves per week of mushrooms no diet was able to meet vitamin D needs.

- To meet the vitamin D AI, the addition of 13, 27, and 44 serves of white button mushrooms per week would be needed for women aged 19-30 years, men aged 51-70 years, and women aged 70 plus years, respectively.

Other nutrients

The addition of mushrooms as a separate sub-category of vegetables had a notable effect on selenium, which is an at-risk nutrient for some population groups in the *Foundation Diets*. This suggests a role for mushrooms in supporting the intake of selenium within a vegetarian diet:

- For women 19-30 years, the addition or substitution of 3 serves/week of mushrooms increased selenium intakes from 97% to 104% RDI, and when 7 serves/week of mushrooms were modelled, selenium intakes increased to 120% of the RDI.
- For men aged 51 to 70 years, the addition of 3 serves of mushrooms/week increased selenium intakes from 93% to 101% RDI, and 7 serves per week took selenium intakes to 114% of the RDI.
- For women aged 70+ years, selenium intakes increased from 79.5% to 105% of the RDI when 7 serves/week of mushrooms were modelled, either by addition or substitution.

What is the nutritional impact of adding mushrooms as a subcategory of vegetables?

The addition of one serve of mushrooms per day was found to make important contributions to both vitamin D and to selenium intakes. Vitamin D is a nutrient of concern for all population groups and selenium is of particular importance within an ovo-lacto vegetarian diet.

Modelling UV-exposed mushrooms as a sub-category of vegetables

The addition of UV-exposed mushrooms to the diet as a separate sub-category of vegetables significantly increased vitamin D intakes across all demographic groups assessed. The impact of the modelling on vitamin D intakes is provided in **Table 6.** The effects of other nutrients are unchanged with UV-exposure.

Effect on vitamin D

Both the Omnivore and Ovo-Lacto Vegetarian diets were able to meet vitamin D requirements across all demographic groups with up to 4 serves of UV-exposed mushrooms added per week:

- **Women aged 19-30 years:** only one serve per week was sufficient for the Omnivore dietary pattern, with 2 serves per week required for the Ovo-Lacto Vegetarian dietary pattern.
- **Men aged 51-70 years:** 2 serves of UV-exposed mushrooms per week were required to meet requirements, regardless of diet.
- **Women aged 70 plus years:** 4 serves of UV-exposed mushrooms per week were required to meet requirements, regardless of diet.

When compared to the modelling results obtained for non-UV-exposed mushrooms, where up to 44 serves of mushrooms per week were needed to reach vitamin D requirements, the consumption of UV-exposed mushrooms is a far more feasible method to make a meaningful impact on vitamin D intakes, across all demographic groups assessed.

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How do the results of the modelling compare to current intakes?

The modelling showed that mushrooms have the potential to make a meaningful contribution to vitamin D intakes, as well other nutrients, if consumed as a separate sub-category of vegetables seven times per week (equivalent to one serve per day). In contrast, one to four serves of UV-exposed mushrooms were sufficient to provide vitamin D requirements for all demographic groups.

Recent sales data [107] in Australia show that Australians purchase an average of 2.57 kg mushrooms per year, equivalent to 50 grams; less than one 75 gram serve per week. The sale and consumption of total vegetables (not including mushrooms or legumes) reached 83.51 kg per year [107], indicating that mushrooms currently sit at around 3% of total vegetable consumption. This suggests that there is large scope to increase mushroom consumption and improve nutritional intake.

Table 5. Effect of the addition of *A. bisporus* (white button) mushrooms as a sub-category of vegetables on daily vitamin D[1] intake within Foundation Omnivore and Ovo-Lacto Vegetarian diets.

DEMOGRAPHIC GROUP	NRV (AI) FOR VITAMIN D (µg/day)	FOUNDATION DIET		+ 3 SERVES MUSHROOMS/WEEK		+ 7 SERVES MUSHROOMS/WEEK		NUMBER OF MUSHROOM SERVES/WEEK TO MEET AI
		VITAMIN D (µg/day)	%NRV	VITAMIN D (µg/day)	%NRV	VITAMIN D (µg/day)	%NRV	
Omnivore diet								
Women 19-30 years	5	3.3	65	3.9	78	5.1	**101**	7
Men 51-70 years	10	4.6	46	5.3	53	6.5	65	19
Women 70+ years	15	4.5	30	5.3	35	6.5	43	36
Ovo-lacto vegetarian diet								
Women 19-30 years	5	1.5	30	2.1	42	3.3	66	13
Men 51-70 years	10	2.2	22	2.9	29	4.1	41	27
Women 70+ years	15	2.1	14	2.9	19	4.1	27	44

[1] Vitamin D_2 and D_3

AI, adequate intake; µg, micrograms; NRV, nutrient reference value.

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Table 6. Effect of the addition of UV-exposed (vitamin D-enhanced) *A. bisporus* (white button) mushrooms as a sub-category of vegetables on daily vitamin D intake[1] within Foundation Omnivore and Ovo-Lacto Vegetarian diets.

DEMOGRAPHIC GROUP	NRV (AI) FOR VITAMIN D (µg/day)	FOUNDATION DIET		+ 1 SERVE UV-MUSHROOMS/WEEK		+ 3 SERVES UV-MUSHROOMS/WEEK		NUMBER OF UV-MUSHROOM SERVES/WEEK TO MEET AI
		VITAMIN D (µg/day)	%NRV	VITAMIN D (µg/day)	%NRV	VITAMIN D (µg/day)	%NRV	
Omnivore diet								
Women 19-30 years	5	3.3	65	6.4	127	13.1	262	1
Men 51-70 years	10	4.6	46	7.8	78	14.5	145	2
Women 70+ years	15	4.5	30	7.7	52	14.5	97	4
Ovo-lacto vegetarian diet								
Women 19-30 years	5	1.5	30	4.6	92	11.3	227	2
Men 51-70 years	10	2.2	22	5.4	54	12.1	121	2
Women 70+ years	15	2.1	14	5.4	36	12.1	81	4

[1] Vitamin D_2 and D_3

AI, adequate intake; µg, micrograms; NRV, nutrient reference value.

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Summary: Classifying mushrooms as its own subcategory would improve nutrient intakes.

- The substitution of “other vegetables” with mushrooms increased vitamin D intakes.
- The use of UV-exposed mushrooms means tha vitamin D requirements can be met with 1 to 4 serves per week, depending on the demographic group.
- The addition of mushrooms to ovo-lacto vegetarian diets not only increased vitamin D intakes, but also had positive effects on selenium intakes.
- Even if mushrooms were added on top of the usual diet, there were minimal effects on energy intakes.

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Summary of Findings

The scientific evidence presented within this report was focused around six key questions, each an important aspect for the development of mushrooms as a separate sub-category of the vegetables core food group within the ADG. The key findings are summarised in **Table 7** below.

Table 7. Key findings of the scientific report relating to a mushrooms sub-category within the vegetables core food group of the Australian Dietary Guidelines.

BIOLOGICALLY DISTINCT	• Mushrooms are not vegetables and belong to a distinct biological kingdom, fungi.
NUTRITIONALLY DISTINCT	• Mushrooms provide a unique set of nutrients to the diet that is different to vegetables. • Mushrooms also contain a different complement of bioactives to vegetables. • Dietary modelling has shown that increasing mushroom intake can make a significant contribution to the intake of key dietary nutrients that vegetables do not provide.
VITAMIN D IS A KEY DISTINGUISHING NUTRIENT	• Mushrooms are a source of vitamin D and, when exposed to UV light, provide >100-300% of dietary needs. • Vitamin D deficiency is a global problem with no clear solution. • Vitamin D intakes in Australia are low and it is difficult to meet vitamin D needs. • There is precedent in dietary guidelines to recognise foods with unique nutrient compositions or different 'distinguishing' nutrients, yet the current ADG do not recognise the unique nutritional composition of mushrooms.
CULINARY DISTINCT	• Mushrooms have unique culinary properties from vegetables including an umami flavour and meat-like texture. • Mushrooms can be used as meat substitutes with comparable or increased liking scores and improved nutrient intakes. • The substitution of meat with mushrooms can also result in costs savings and environmental benefits.
UNIQUE HEALTH BENEFITS	• Unlike vegetables, mushrooms improve vitamin D status when UV-exposed and may reduce ovarian cancer risk. • This may be due to their bioactive profile, that is distinct from vegetables.
VALIDATED BY DIETARY MODELLING	• Current recommended diets in the ADG are deficient in vitamin D and vegetarian diets are deficient in vitamin D and selenium. • The creation of a new "mushrooms" subcategory of vegetables produced notable increases in vitamin D intakes for adult males and females.

	• This effect is amplified with UV-exposed mushrooms, where vitamin D needs were met with as little as 1 x 75 gram serve per week for women aged 19-30 years. • One 75 g serve of mushrooms per day also enabled ovo-lacto vegetarian adults to meet their selenium requirements.

Conclusions

The Australian Dietary Guidelines (ADG) aim to support health and provide Australians with a sufficient intake of all nutrients within a diet. This is achieved by grouping foods based on similar nutritional compositions. However, the current ADG do not meet vitamin D needs and do not acknowledge the distinct nutritional composition of mushrooms.

Findings from a scope of the scientific and supporting literature were combined with dietary modelling. Mushrooms have a unique nutritional composition, including being a source of vitamin D, which is explained by their unique biology. When exposed to UV-light, vitamin D content increases substantially, and mushrooms make a significant impact on vitamin D status. Dietary modelling confirmed that categorising mushrooms as its own subcategory of foods within the 'Vegetables and legumes/beans' food group would have a notable impact on vitamin D intakes. Their culinary properties are also diverse to vegetables, and they can help to reduce sodium and saturated fat intake, and increase fibre and potassium intake, via meat replacement in meals.

Together, the totality of the evidence shows that revamping the position of mushrooms within the ADG has a beneficial effect on modelled micronutrient intakes in the Australian population and the potential to make a significant contribution to solving current public health problems.

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Appendices

Appendix 1. Methodology

Two approaches were used to source and assess the scientific evidence:

- Questions 1 to 5 were investigated via a scope of the scientific literature.
- Question 6 was answered via dietary modelling, based on the approach described during the revision of the Australian Guide to Healthy Eating [6].

Literature scope

Search strategy

Previously developed collateral on mushroom science was examined in the first instance to inform the scope and period of the search. These included:

- 2020 published scoping review: "Examining the health effects and bioactive components in *Agaricus bisporus* mushrooms: a scoping review" [3].
- 2021 Expert Roundtable Discussion white paper: "Fungi Foods: Where do they fit in a plant-based diet?" [4].
- 2019 General Practice Conference and Exhibition (GPCE) Vitamin D presentation [5].

A targeted search of the scientific literature was conducted in March 2023 using the PubMed (including Medline) database. Search terms for Questions 1 to 5 are detailed below and were limited to placement within the title and abstract of scientific publications. Searches were supported by data from:

- Australian Food composition database [14].
- Revision of Australian Guide to Healthy Eating modelling [6].
- National Nutrition and Physical Activity Survey (NNPAS) 2011-12: Vitamin D results [53].
- Sales and (implied) consumption data [107].
- 2020 Scoping Review [3].
- Online cost information; Woolworths and Coles supermarkets [108, 109].

Q1: Biological classification vs vegetables

COMPONENT OF SEARCH	SEARCH STRATEGY
Mushrooms	Mushroom* OR fungi OR funghi

COMPONENT OF SEARCH	SEARCH STRATEGY
AND Biology	Kingdom OR biolog* OR biological classification OR gene* OR phylogenetic tree OR DNA OR decomposer OR ecosystem
AND Vegetables	Vegetable* OR plant* OR animal* OR producer OR consumer

Q2: Nutritional composition and contribution to the diet vs vegetables

COMPONENT OF SEARCH	SEARCH STRATEGY
Mushrooms	Mushroom OR A. bisporus OR Agaricus bisporus OR shiitake OR shitake OR cremini OR portabella OR portobello OR oyster mushroom OR button mushroom OR Lentinula edodes OR L. edodes OR Pleurotus ostreatus OR P. ostreatus OR enoki OR Flammulina filiformis OR F. filiformis OR shimeji OR Hypsizygus tessellatus OR H. tessellatus
AND Nutritional composition/contribution to the diet	Nutrition OR nutritional composition OR nutrient OR vitamin OR mineral OR bioactive OR phytonutrient OR phytochemical OR dietary intake OR diet quality OR eating patterns OR consumption OR ergothioneine OR beta-glucan OR glutathione
AND Vegetables	Vegetable* OR plant* OR animal*

Q3: Significance of mushrooms as a source of vitamin D

COMPONENT OF SEARCH	SEARCH STRATEGY
Vitamin D	Vitamin D OR calciferol OR ergocalciferol
AND Intake	Deficiency OR insufficiency OR inadequate OR intake
AND Mushrooms	Mushroom OR A. bisporus OR Agaricus bisporus OR shiitake OR shitake OR cremini OR portabella OR portobello OR oyster mushroom OR button mushroom OR Lentinula edodes OR L. edodes OR Pleurotus ostreatus OR P. ostreatus OR enoki OR Flammulina filiformis OR F. filiformis OR shimeji OR Hypsizygus tessellatus OR H. tessellatus
AND Significance of contribution to diet	Source OR vegan OR vegetarian OR UV OR conversion

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Q4: Culinary properties of mushrooms

COMPONENT OF SEARCH	SEARCH STRATEGY
Mushrooms	Mushroom OR A. bisporus OR Agaricus bisporus OR shiitake OR shitake OR cremini OR portabella OR portobello OR oyster mushroom OR button mushroom OR Lentinula edodes OR L. edodes OR Pleurotus ostreatus OR P. ostreatus OR enoki OR Flammulina filiformis OR F. filiformis OR shimeji OR Hypsizygus tessellatus OR H. tessellatus
Culinary properties	Culinary OR cooking OR replacement OR taste OR texture OR sensory OR umami
Nutritional properties	Nutritional profile OR nutritional composition OR nutrient* OR bioactiv*

Q5: Unique health effects of mushrooms

COMPONENT OF SEARCH	SEARCH STRATEGY
Mushrooms	Mushroom OR A. bisporus OR Agaricus bisporus OR shiitake OR shitake OR cremini OR portabella OR portobello OR oyster mushroom OR button mushroom OR Lentinula edodes OR L. edodes OR Pleurotus ostreatus OR P. ostreatus OR enoki OR Flammulina filiformis OR F. filiformis OR shimeji OR Hypsizygus tessellatus OR H. tessellatus
AND Health effects	Health OR benefit OR adverse OR cardiovascular OR metabolic OR anthropometric OR cancer OR mortality OR immun* OR inflammation OR appetite OR satiety OR gastrointestinal OR digestive OR prebiotic OR gut microbiota OR microbiome OR cholesterol OR diabetes OR blood glucose OR insulin OR hyperlipidemia OR hypertension OR blood pressure OR cognitive
AND Economic effects	Economic OR nutrient density to cost ratio OR affordability
AND Comparison to vegetables	Vegetable OR plant
AND Substitution for meat	Substitution OR substituted OR meat alternative

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Publication types included systematic literature reviews (SLRs), meta-analyses (MAs), randomised controlled trials (RCTs), observational studies, and narrative reviews. Where many publications were identified for a research question, search hits were limited to prioritise the most recent (published in the last ten years) and highest levels of evidence, considered to be:

- SLRs or MAs of RCTs or observational studies;
- Original RCTs; and
- Original observational studies.

A secondary targeted Google search, including Google Scholar, was conducted to identify additional scientific and grey literature, with a specific focus on Australian Food Composition Database (AFCD) files [14], the National Nutrition and Physical Activity Survey (NNPAS) 2011-12 [78], and mushroom consumption or sales data, where applicable.

Study screening and selection

Studies were screened by title and abstract to determine their relevancy to each research question. Where many studies were identified by the search strategy, even after limiting by date and study type, studies published in the last 5 years were prioritised. Selection was also targeted towards studies in the Australian population where available, or similar populations (e.g., New Zealand, America, Canada, Europe) where Australian-specific data were not available.

Data extraction and synthesis

For each study selected, data were extracted and synthesised in a narrative manner, with a focus on the information applicable to the relevant research question from the highest level of evidence, based on the National Health and Medical Research Council (NHMRC) framework [110]:

- **High:** Systematic literature review (SLR) or meta-analysis (MA) of randomised controlled trials (RCTs) or observational studies.
- **Moderate to high:** RCT.
- **Moderate:** Controlled non-randomised trials and controlled observational studies.
- **Low to moderate:** Uncontrolled intervention or longitudinal observational studies; cross-sectional studies.
- **Low:** Pre-clinical studies (animal and *in vitro*).

Modelling

Overview

The aim of the modelling is to quantify the effect on the nutrition composition of the *Foundation Diet*, as used in the revision of the Australian Dietary Guidelines (ADG) [6], if mushrooms are removed from the "other vegetables" category of the vegetables core food group, and a new “mushrooms” vegetables sub-category is created. The effect of different serve numbers, both in substitution for serves of “other vegetables” and in addition to the current recommended vegetables serves per week will be assessed. Baseline modelling inputs (such as composite food group composition within the diet) and outputs (such as nutritional composition of *Foundation Diets*) will be sourced from the ADG modelling [6] where applicable.

Rationale for refined modelling approach

The ADG modelling was focused on four different Foundation Diets (omnivore, ovo-lacto vegetarian, rice-based, and pasta-based) for 18 different demographic groups (based on age and sex), as well as pregnancy and lactation [6]. For the current modelling, which is intended to provide proof-of-concept only, rather than serve as a replacement for the ADG modelling, two different Foundation Diets were modelled in three demographic groups.

Selected diets were based on having largest degree of difference in nutritional composition:

- Omnivore
- Ovo-lacto vegetarian

The three demographic groups chosen for modelling were:

- Women 19-30 years
- Men 51-70 years
- Women 71+ years

These demographic groups were selected according to the following rationale, based on vitamin D needs and the prevalence of deficiency within the population [53]:

- All adequate vitamin D intakes are represented; children and adults up to 50 years have an AI of 5 µg/day, adults 51 to 70 years have an AI of 10 µg/day, and adults over 70 years have an AI of 15 µg/day [60].
- Age is a key predictor of vitamin D deficiency:
    - Children have low levels of vitamin D deficiency [53].
    - The highest levels of vitamin D deficiency are seen in adults 18 to 44 years [53].
    - While older adults are less likely than younger adults to be vitamin D deficient due to higher rates of supplement use, the prevalence of deficiency increases over the age of approximately 75 years [53].

The nutritional data used for the current modelling was sourced from the AFCD [14]. While this approach is in contrast to that used for the ADG modelling, which sourced nutritional data from the AUSNUT07 files [6], the AFCD represents the most recent nutritional information available and is therefore most applicable to current intakes.

The ADG modelling outputs did not include all nutrients for which there is an NRV. The current modelling was therefore limited to those nutrients included within the ADG modelling for Foundation Diets [6]:

- **Energy:** with and without dietary fibre
- **Macronutrients**: protein, fat, carb, sugars, starch, dietary fibre, saturated fat, MUFA, PUFA, LA, ALA, LCn3, cholesterol
- **Vitamins:** thiamin, vitamin A (total retinol equivalents), vitamin C, folic acid, riboflavin, niacin (equivalents), folate, vitamin D, vitamin E, vitamin B6, vitamin B12
- **Minerals:** calcium, iodine, iron, magnesium, zinc, phosphorus, potassium, sodium, selenium

Modelling methodology

The modelling was carried out over 3 steps.

- Creation of modelling database:
    a. The nutritional composition of original *Foundation diets* from ADG modelling document was sourced [6]. The *Foundation diets* were designed to attain the NRV for each age group within the energy needs of the smallest and very sedentary (physical activity level of 1.4) individual in that group.
    b. This was repeated for each of omnivore and ovo-lacto diets, for each selected demographic group, to create six different modelling spreadsheets.

- Creation of two new vegetable sub-categories: "other vegetables - no mushrooms"; and "mushrooms":
    a. The information presented in the ADG modelling was used to determine the overall nutritional composition of the "other vegetables" subcategory for each demographic group. The data sourced included: vegetables included in the "other vegetables" subcategory; the relative proportion of each vegetable within "other vegetables" for each demographic group; and the nutritional composition of each included vegetable as presented in the AFCD. This subcategory was hereby referred to as "other vegetables – original".
    b. The contribution of mushrooms (including nutritional composition) was removed from the "other vegetables – original" sub-category for each demographic group, and the relative percentage contribution of each nutrient was normalised (to equal 100%), to create the "other vegetables – no mushrooms" subcategory.
    c. A "mushrooms" subcategory was created, with two iterations:
        i. White button mushrooms (*A. bisporus*) using AFCD data and the approach used for Foundation diet modelling; this approach uses the average composition of raw and cooked white button mushroom, with no fat included.
        ii. UV-treated *A. bisporus* (increased vitamin D levels) using AFCD data and the approach used for Foundation diet modelling; this approach uses the average composition of raw and cooked UV-treated white button mushroom, with no fat included.

d. One serve of any one vegetables subcategory was taken to be 75 grams, as specified in the Australian Dietary Guidelines [1].

- Modelling of mushrooms as a separate sub-category of vegetables (for each Foundation diet and for each demographic group):
    a. The nutritional composition of “other vegetables - original” was subtracted from the nutritional composition of each *Foundation diet* for each demographic group.
    b. The “other vegetables – no mushrooms” and “mushrooms” nutritional composition was added back on a number of serves per week basis using two models:
        i. Substitution: the “other vegetables – no mushrooms” sub-category was substituted for the “mushrooms” sub-category by one serve per week at a time. For example: 1. 14 serves of “other vegetables – no mushrooms” and 0 serves of “mushrooms”; 2. 13 serves of “other vegetables – no mushrooms” and 1 serve of “mushrooms”.
        ii. Addition: the mushrooms” sub-category” was added to the diet, whilst maintaining the current number of servings for the “other vegetables – no mushrooms” sub-category. For example: 1. 14 serves of “other vegetables – no mushrooms” and 1 serve of “mushrooms”; 2. 14 serves of “other vegetables – no mushrooms” and 2 serves of “mushrooms”.
    c. The total nutritional composition of each diet for each demographic group was calculated per week and per day.
    d. The ability of each diet to meet the NRV (RDI or AI) for each applicable nutrient was calculated. RDI was used in place of EAR as this was the approach used in the Revision of the Australian Dietary Guidelines [6], based on the rationale that the models aimed to meet the nutrient requirements of most individuals within each demographic group (age and sex).

Appendix 2. The nutritional composition of mushrooms.

Table A1. Macronutrient composition[1] of predominant mushroom varieties in Australia.

MUSHROOM VARIETY	ENERGY	PROTEIN	TOTAL FAT	SATURATED FAT	TOTAL CARBOHYDRATE	TOTAL SUGARS	DIETARY FIBRE
	kJ	g	g	g	g	g	g
Common varieties							
White button (*Agaricus bisporus*)	87	2.2	0.40	0.08	1.3	0	1.4
Brown button (*Agaricus bisporus*)	95	3.3	0.30	0.02	0.7	0	1.7
Portobello (*Agaricus bisporus*)	91	2.5	0.31	0.02	1.2	0.3	1.8
White button UV-exposed (*Agaricus bisporus*)	87	2.2	0.40	0.08	1.3	0	1.4
Exotic varieties							
Oyster (*Pleurotus ostreatus*)	138	2.9	0.19	0	1.1	0	2.8
King Oyster (*Pleurotus eryngii*)	159	2.4	0.31	0	1.1	0	3.0
Shiitake (*Lentinula edodes*)	151	2.4	0.20	0	1.2	0	4.2
Enoki (*Flammulina filiformis*)	155	2.4	0.24	0	3.1	0	2.9
Shimeji (*Hypsizygus tessellatus*)	138	2.2	0.45	0	0.7	0	3.1

[1] Nutrient data taken from the Australian Food Composition database [14] for white button mushrooms and UV-exposed white button mushrooms, the USDA Food Data Central database [24] and New Zealand Food Composition database [111] for portobello and brown button mushrooms, and USDA Food Data Central database [24] for exotic mushroom varieties.
g, grams; kJ, kilojoules

Table A2. Vitamin composition[1] of predominant mushroom varieties in Australia.

MUSHROOM VARIETY	VITAMIN A (RE)	THIAMINE	RIBOFLAVIN	NIACIN	VITAMIN B5	VITAMIN B6	BIOTIN	FOLATE (DFE)	VITAMIN B12	CHOLINE	VITAMIN C	VITAMIN D2	VITAMIN D3 (equivalents)	VITAMIN E	VITAMIN K
	µg	mg	mg	mg	mg	mg	µg	µg	µg	mg	mg	µg	µg	mg	µg
Common varieties															
White button (*Agaricus bisporus*)	0	0.06	0.00	3.82	1.2	0.01	8.5	22	0	NR	0.0	2.0	2.14	0	NR
Brown button (*Agaricus bisporus*)	NR	0.06	0.58	5.29	NR	0.20	12.6	0	0	NR	0.0	0.0	NR	0	NR
Portobello (*Agaricus bisporus*)	NR	0.05	0.51	4.45	1.4	0.16	11.1	0	0	NR	0.3	0.0	NR	0.2	0
White button UV-exposed (*Agaricus bisporus*)	0	0.06	0.00	3.82	1.2	0.01	8.5	22	0	NR	0	24	24.18	0	0
Exotic varieties															
Oyster (*Pleurotus ostreatus*)	NR	0.07	0.24	5.75	NR	0.10	7.0	NR	NR	NR	NR	0.04	NR	NR	NR
King Oyster (*Pleurotus eryngii*)	NR	0.01	0.24	6.45	NR	0.12	10.8	NR	NR	NR	NR	0.07	NR	NR	NR
Shiitake (*Lentinula edodes*)	NR	0.001	0.22	2.74	NR	0.16	6.1	NR	NR	NR	NR	0.06	NR	NR	NR
Enoki (*Flammulina filiformis*)	NR	0.01	0.24	6.99	NR	0.12	12.5	NR	NR	NR	NR	0.00	NR	NR	NR
Shimeji (*Hypsizygus tessellatus*)	NR	0.01	0.21	6.40	NR	0.02	8.1	NR	NR	NR	NR	0.37	NR	NR	NR

[1] Nutrient data taken from the Australian Food Composition database [14] for white button mushrooms and UV-exposed white button mushrooms, the USDA Food Data Central database [24] and New Zealand Food Composition database [111] for portobello and brown button mushrooms, and USDA Food Data Central database [24] for exotic mushroom varieties.
DFE, dietary folate equivalents; µg, micrograms; mg, milligrams; NR, not reported; RE, retinol equivalents.

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Table A3. Mineral composition[1] of predominant mushroom varieties in Australia.

MUSHROOM VARIETY	CALCIUM	CHROMIUM	COPPER	FLUORIDE	IODINE	IRON	MAGNESIUM	MANGANESE	MOLYBDENUM	PHOSPHORUS	POTASSIUM	SELENIUM	SODIUM	ZINC
	mg	µg	mg	µg	µg	mg	mg	mg	µg	mg	mg	µg	mg	mg
Common varieties														
White button (*Agaricus bisporus*)	3.0	0	0.37	35	0.0	0.45	11.0	0.075	2.3	110	360	16.0	9.0	0.06
Brown button (*Agaricus bisporus*)	3.0	NR	0.29	NR	0.3	0.29	10.1	0.0575	NR	97	350	14.2	2.3	0.48
Portobello (*Agaricus bisporus*)	2.0	NR	0.25	NR	0.0	0.17	9.5	0.0485	NR	96	360	17.4	4.5	0.40
White button UV-exposed (*Agaricus bisporus*)	3.0	0	0.37	35	0.0	0.45	11.0	0.075	2.3	110	360	16.0	9.0	0.06
Exotic varieties														
Oyster (*Pleurotus ostreatus*)	2.5	NR	0.11	NR	NR	0.70	13.9	0.086	NR	86	282	1.4	NR	0.68
King Oyster (*Pleurotus eryngii*)	2.5	NR	0.05	NR	NR	0.34	13.5	0.091	NR	90	294	1.2	NR	0.63
Shiitake (*Lentinula edodes*)	1.0	NR	0.05	NR	NR	0.14	14.1	0.173	NR	76	243	1.2	NR	0.76
Enoki (*Flammulina filiformis*)	1.0	NR	0.09	NR	NR	1.28	12.8	0.09	NR	84	402	2.5	NR	0.48
Shimeji (*Hypsizygus tessellatus*)	0.0	NR	0.07	NR	NR	0.74	10.5	0.156	NR	86	376	0.4	NR	0.50

[1] Nutrient data taken from the Australian Food Composition database [14] for white button mushrooms and UV-exposed white button mushrooms, the USDA Food Data Central database [24] and New Zealand Food Composition database [111] for portobello and brown button mushrooms, and USDA Food Data Central database [24] for exotic mushroom varieties.
µg, micrograms; mg, milligrams; NR, not reported

Table A4. Bioactive composition[1] of predominant mushroom varieties of Australia.

MUSHROOM VARIETY	BIOACTIVE COMPOUNDS PRESENT IN MUSHROOMS					
	BETA-GLUCAN	CHITIN	PHYTOSTEROLS	ERGOTHIONEINE	GLUTATHIONE	OTHER IDENTIFIED BIOACTIVES[2]
Common varieties						
White button (*Agaricus bisporus*)	8.6-12.3 g/100 g DM [21, 22, 112]; 4.2 g/100 g CW [25]; 0.75-1.4 g/100 g FW [24, 25]	5.6-7.6 g/100 g DM [27]; 0.7 g/100 g CW [25]; 0.6 g/100g FW [25]	65.0 mg/100 g FW [24]	3-4 mg/100 g FW [24, 30]	6 mg/100 g FW [30]	Phenolic acids, flavonoids, hydrobenzoic acid derivatives, ACE inhibitory peptide 1, 2, and 3, fucogalactan, lectin, tyrosinases, pyrogallol.
Brown button (*Agaricus bisporus*)	8.8-10.1 g/100 g DM [21, 22, 112]; 0.92 g/100 g FW [24]		64.0 mg/100 g FW [24]	1-2.5 mg/100 g FW [24, 30]	3.4 mg/100 g FW [30]	
Portobello (*Agaricus bisporus*)	1.2 g/100 g FW [24]		57.3 mg/100 g FW [24]	1.6-2 mg/100 g FW [24, 30]	3.7 mg/100 g FW [30]	
Exotic varieties						
Oyster (*Pleurotus ostreatus*)	24.2 g/100 g DM [22, 112]; 0.2 g/100 g CW [25]; 0.1-3.0 g/100g FW [24, 25, 113]	2.9-5.1 g/100 g DM [27]; 0.6 g/100 g CW [25]; 0.3 g/100 g FW [25];	68.6 mg/100 g [24]	10.3-14 mg/100 g FW [24, 30]	15.4 mg/100 g FW [30]	β-carotene, cinnamic acid, flavonoids, phenols, P. ostreatus peptide (POP), pleurostrin, homogentisic, *p*-coumaric acid.
King Oyster (*Pleurotus eryngii*)	15.3 g/100 g DM [22, 112]; 4.42 g/100 g FW [24]		55.6 mg/100 g [24]	24 mg/100 g FW [24]	NA	Heteropolysaccharide acid, laccase, polysaccharide-protein complex, eryngin, eryngiolide A.

MUSHROOM VARIETY	BIOACTIVE COMPOUNDS PRESENT IN MUSHROOMS					
	BETA-GLUCAN	CHITIN	PHYTOSTEROLS	ERGOTHIONEINE	GLUTATHIONE	OTHER IDENTIFIED BIOACTIVES[2]
Shiitake (*Lentinula edodes*)	20-25.3 g/100 g DM [21, 22, 112]; 2.8 g/100 g FW [24]	5.46-8.07 g/100 g DM [27]	72.5 mg/100 g [24]	11 mg/100 g FW [24, 30]	10.1 mg/100 g FW [30]	Lentinan, phenols, flavonoids, eritadenine.
Enoki (*Flammulina filiformis*)	2.18 g/100 g FW [24]	NA	54.9 mg/100 g [24]	26 mg/100 g FW [24]	NA	NA
Shimeji (*Hypsizygus tessellatus*)	2.92 g/100 g FW [24]	NA	71.5 mg/100 g [24]	5 mg/100 g FW [24]	NA	NA

[1] References for beta-glucan, chitin, phytosterols, ergothioneine, and glutathione provided in their respective columns.

[2] References for other identified bioactives were [33-41]. Compositional information was not available.

CW, cooked weight; DM, dry matter; FW, fresh weight; g, grams; mg, milligrams; NA, information not available.

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Appendix 3. Culinary processes and the nutritional composition of mushrooms

Table A5. The effect of culinary processes on the nutrient and bioactive content[1] of mushrooms[2]

CULINARY PROCESS	NUTRIENT OR BIOACTIVE COMPOUND							
	VITAMIN D2	VITAMIN C	ERGOSTEROL	BETA-GLUCAN	ERGOTHIONEINE	FLAVONOIDS	PHENOLS	ANTIOXIDANT ACTIVITY
Cooking								
Baking [13, 41] *(70 to 200 °C for 10 to 90 mins)*	↓ 26 to 38% reduction	NR	NR	NR	NR	NR	NR	NR
Blanching or simmering [41] *(10 to 780 seconds, 90 to 240 °C for 10 to 780 seconds)*	NR	↓ up to 89%	NR	NR	NR	↓ up to 75%	↓ up 79%	NR
Boiling [13, 41, 47] *(10 to 30 mins)*	↓ 20 to 38%	NR	NR	↓ 23%; ↑ up to 31%	NR	NR	↓ 31 to 62%	↓ 10%
Grilling [41, 47]	NR	NR	NR	↓ 5.2%; ↑ up to 11%	NR	NR	↓ 8%	↓ 40%; ↑ over 100%
Frying [13, 41] *(low and high heat, up to 20 mins)*	↓ 12%	NR	NR	↓ up to 58%	NR	NR	↓ 28%	↓ 40%; ↑ 10%
Microwave [47]	NR	NR	NR	↑ 4%	NR	NR	↓ 6%	↑ 31%
Storage								
Refrigeration [13] *(1 to 2 weeks)*	↔ 8 days; ↓ up to 25% after 14 days	NR	NR	NR	NR	NR	NR	NR

CULINARY PROCESS	NUTRIENT OR BIOACTIVE COMPOUND							
	VITAMIN D2	VITAMIN C	ERGOSTEROL	BETA-GLUCAN	ERGOTHIONEINE	FLAVONOIDS	PHENOLS	ANTIOXIDANT ACTIVITY
Dark dry conditions [13] *(mushroom powder, up to 18 months)*	↓ 35% by 8 months; 52% by 18 months	NR	NR	NR	NR	NR	NR	NR
Drying								
Freeze-drying [41] *(-40 °C for 72 hours)*	NR	NR	↔; ↓ up to 15%	NR	↓ 2 to 21%	NR	NR	NR
Hot air drying [41] *(45 to 100 °C for 20 hours)*	↓ 34%; ↑ up to 9%	NR	↓ 1 to 13%	NR	↓ 12 to 36%	NR	NR	NR
Microwave drying [41]	↓ 15 to 33%	NR	NR	NR	NR	NR	NR	NR

[1] References for the effects of each culinary process provided in the appliable row.

[2] All mushroom varieties, including *A. bisporus*, *P. ostreatus*, *P. eryngii*, and *L. edodes.*

NR, not reported; ↓, decrease; ↑, increase; ↔, no change.

Appendix 4. The health effects of mushrooms

Table A6. Summary of the health effects of mushrooms in the recent research (June 2019 to March 2023).

HEALTH OUTCOME	STUDIES IDENTIFIED	MUSHROOM TYPES	FINDINGS	DOSE	TAKE-HOME	REFERENCES
Vitamin D status	Scoping review, n=1; SLR, n=1; RCT, n=2	*A. bisporus* (including UV-exposed); NR	↑ serum 25(OH)D_2; ↓ serum 25(OH)D_3	Dose equivalent of 352 to 28,000 IU vitamin D/day	• Intake of vitamin D from UV-treated mushrooms can support sufficient vitamin D status.	[3, 67, 91, 92]
Inflammation and immune function	Scoping review, n=1; RCT, n=1	*A. bisporus, L. edodes*	*A. bisporus*: ↓ TNF- α; ↑ ergothioneine, ORAC, sIgA; ↔ IL-2, IL-4, IL-10, IL-12, IL-13, IL-17, interferon-γ, serum creatinine; *L. edodes*: ↔ TNF-α, ox-LDL; Both mushrooms: ↔ IL-1β, IL-6	*A. bisporus*: 8 and 16 g/day (powder), 100 g/day (fresh); *L. edodes*: 10.4 g/day extract.	• Inconsistent effects on inflammatory and immunomodulatory markers that may depend on the type of mushroom. • No adverse effects. • Beneficial effects of fresh *A.bisporus* on marker of mucosal immunity.	[3, 93]
Satiety and energy intake	Scoping review, n=1; RCT, n=1	*A. bisporus, P. ostreatus*	Both: ↓ hunger; ↔ satiety. *A. bisporus*: ↓ PFC; ↑ fullness; ↔ ↓ energy intake. *P. ostreatus*: ↔ fullness, DTE, ghrelin, GIP.	20 g powder (8.1 g β-glucans) of oven-dried *P. ostreatus*; 226 g/day fresh *A. bisporus.*	• Consistent effect on subjective hunger only. • Best outcomes observed with *A. bisporus.*	[3, 94]

HEALTH OUTCOME	STUDIES IDENTIFIED	MUSHROOM TYPES	FINDINGS	DOSE	TAKE-HOME	REFERENCES
Cancer	Scoping review, n=1; SLR and MA, n=1	*A. bisporus,* NR	↓ risks of ovarian cancer (32%), total cancer (34%), breast cancer (35%), levels of PSA ↓ risk of total cancer at 18 g/day (45%)	Number of times per week (never to > 5 times per week); 0 to 18.3 g/day fresh; 3 to 29 g/1000 kcal; 4-14 g extract/day, equivalent to 40-140 g fresh.	• Reduced risk of range of total, breast, and ovarian cancers with higher intake of mushrooms.	[3, 95]
Gastrointestinal	Scoping review, n=1; RCT, n=1	*A.bisporus, L.edodes*	↑ stool weight, gut microbiota composition; ↔ adverse effects, bowel regularity, SCFAs; ↓ bowel strain, fecal odour, halitosis.	50 to 1000 mg/day extract; 226 g/day fresh (*A. bisporus*); 10.4 g/day powder (*L. edodes*).	• Beneficial effects on digestive function and gut microbiota composition with both *A. bisporus* and *L. edodes.*	[3, 93]
Cardiometabolic markers	Scoping review, n=1; SLR, n=3; RCT, n=4	*A. bisporus, P. ostreatus, L.edodes, G. lucidum, P. cystidiousus,* NR	↔ ↓ glucose (fasting and postprandial), bodyweight; ↓ TC, LDL-C, TG; NEFA; visceral fat; ↑ HDL-C, adiponectin, GLP-1; ↔ ↓↑ blood pressure; ↔ insulin.	2 g/kgbw/day; 100-260 g/day fresh; 3 to 30 g/day powdered; 50 mg/kgbw powdered; 5 servings to 1 kg fresh per week; higher vs lower intake.	• Overall beneficial effect but mixed effects on some metabolic markers. • Exposure to *L. edodes* triggered dermatitis in 10% of individuals sensitive to the mushroom.	[3, 93, 94, 97-101]
Cardiometabolic disease risk	SLR, n=2	*A. bisporus, P. ostreatus, L.edodes, G. lucidum, P. cystidiousus,* NR	↔ risks of CVD, CHD, stroke, T2DM.	3.5 to 15 g powder/day; 100 to 260 g/day fresh; 5 servings per week; higher vs lower intake.	• No association between mushroom intake and cardiometabolic disease risk.	[98, 99]

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HEALTH OUTCOME	STUDIES IDENTIFIED	MUSHROOM TYPES	FINDINGS	DOSE	TAKE-HOME	REFERENCES
Cognitive function	RCT, n=1; cross-sectional, n=1	*A. bisporus*	↑ 2/5 tests of cognitive function; ↔ 3/5 tests of cognitive function	Dose equivalent of 600 IU vitamin D/day; higher (13.4 g/1000 kcal)/day) vs lower mushroom intake	• Mixed effects on cognitive function.	[92, 103]
Mood	RCT, n=1; cohort, n=1	*A. bisporus*	RCT: ↔ mood; Cohort: ↓ depressive symptoms	Rare to more than 90 g per week; dose equivalent of 600 IU vitamin D/day.	• Mixed effects on mood and mental health symptoms. • Possible support for depression.	[92, 104]
Mortality	SLR, n=1; MA of PCs, n=1; PC, n=1	*A. bisporus, P. ostreatus, L.edodes, P. cystidiousus,* NR	↓ risk of all-cause mortality (6-35%); ↔ risk of CVD mortality.	3.5 to 15g powder/day; 100 to 260 g/day fresh; 5 servings per week; higher vs lower intake.	• Lower risk of all-cause mortality only.	[99, 105, 106]
Quality of life	RCT, n=1	*L. edodes* mycelia extract	↑ taste-related QOL	6 g/day	• Mycelia extract can improve QOL in chemotherapy patients.	[114]

25(OH)D_2, 25-hydroxy vitamin D_2; 25(OH)D_3, 25-hydroxy-vitamin D_3; g, grams; CHD, coronary heart disease; CVD, cardiovascular disease; DTE, desire to eat; GIP, gastric inhibitory peptide; GLP-1, glucagon-like peptide 1; HDL-C, high density lipoprotein cholesterol;IL, interleukin; IU, international units; kcal, calories; LDL-C, low density lipoprotein cholesterol; MA, meta-analysis; mg, milligrams; NEFA, non-esterified free fatty acids; ox-LDL, oxidised low density lipoprotein; ORAC, oxygen radical absorbance capacity; PFC, prospective foods consumption; PSA, prostate specific antigen; QOL, quality of life; RCT, randomised controlled trial; SCFAs, short chain fatty acids; sIgA, secretory immunoglobulin A; SLR, systematic literature review; T2DM, type 2 diabetes mellitus; TC, total cholesterol; TG, triglycerides; TNF-α, tumour necrosis factor alpha; ↓, decrease; ↑, increase; ↔, no change.

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Appendix 5. Dietary modelling results

Table A7. Women 19-30 years Omnivore diet

NUTRIENT[1]	NRV (RDI/AI)	OMNIVORE FOUNDATION DIET		SUB[2]. N=3 SERVES/WEEK		SUB[2]. N=7 SERVES/WEEK		ADD[3]. N=3 SERVES/WEEK		ADD[3]. N=7 SERVES/WEEK	
		/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV
Macronutrients											
Energy, excl. fibre (kJ)	NA	7125.3	NA	7123.9	NA	7122.0	NA	7164.3	NA	7216.4	NA
Energy, incl, fibre (kJ)	7100	7384.0	104.0	7382.8	104	7381.2	104	7417.4	104	7461.9	105
Protein (g)	46	101.2	220.0	101.6	221	102.4	223	102.0	222	103.3	225
Carbohydrate, total (g)	NA	206.3	NA	205.9	NA	205.2	NA	207.1	NA	207.9	NA
Sugars, total (g)	44	91.1	207.0	90.4	205	89.1	202	91.4	208	91.4	208
Starch (g)	NA	114.1	NA	114.0	NA	113.9	NA	114.2	NA	114.2	NA
Dietary fibre (g)	25	34.0	136.1	33.9	136	33.8	135	34.7	139	35.5	142
Fat, total (g)	66	52.4	79.4	52.3	79	52.3	79	52.6	80	52.8	80
SFA, total (g)	19	17.8	93.7	17.8	94	17.8	94	17.8	94	17.9	94
MUFA, total (g)	24	17.6	73.4	17.5	73	17.3	72	17.7	74	17.7	74
PUFA, total (g)	24	12.8	53.5	12.9	54	13.0	54	12.9	54	13.0	54
Linoleic acid (g)	8	11.6	145.5	11.7	146	11.8	148	11.7	146	11.9	148
Alpha linolenic acid (g)	0.8	0.9	112.5	0.9	113	0.9	113	0.9	113	0.9	113
LCn-3, total (mg)	90	214.5	238.3	214.5	238	214.5	238	214.5	238	214.5	238
Cholesterol (mg)	NA	216.6	NA	216.6	NA	216.6	NA	216.6	NA	216.6	NA
Vitamins											
Thiamin (mg)	1.1	1.6	143.6	1.6	144	1.6	146	1.6	144	1.6	147
Riboflavin (mg)	1.1	2.5	226.4	2.5	226	2.5	225	2.5	226	2.5	226
Niacin equivalents (mg)	14	51.5	367.7	52.5	375	54.5	390	52.7	377	55.0	393
Vitamin B6 (mg)	1.3	1.7	133.8	1.7	133	1.7	130	1.8	136	1.8	136
Folate (DFE) (µg)	400	496.3	124.1	495.5	124	494.2	124	504.5	126	515.2	129
Folic acid (µg)	NA	757.5	NA	757.5	NA	757.5	NA	757.5	NA	757.5	NA

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NUTRIENT[1]	NRV (RDI/AI)	OMNIVORE FOUNDATION DIET		SUB[2]. N=3 SERVES/WEEK		SUB[2]. N=7 SERVES/WEEK		ADD[3]. N=3 SERVES/WEEK		ADD[3]. N=7 SERVES/WEEK	
		/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV
Vitamin B12 (µg)	2.4	5.9	247.5	5.9	248	5.9	248	5.9	248	5.9	248
Vitamin A (RE) (µg)	700	1435.6	205.1	1425.1	204	1405.0	201	1440.2	206	1440.2	206
Preformed retinol (µg)	NA	350.1	NA	350.1	NA	350.1	NA	350.1	NA	350.1	NA
Provitamin A (µg)	NA	6522.3	NA	6459.4	NA	6338.9	NA	6549.9	NA	6549.9	NA
Vitamin C (mg)	45	125.3	278.4	118.2	263	104.7	233	128.3	285	128.3	285
Vitamin D (µg)	***5***	***3.3***	***65.4***	***3.9***	***78***	***5.1***	***101***	***3.9***	***78***	***5.1***	***102***
Vitamin E (mg)	7	9.1	130.1	9.0	129	8.8	126	9.2	131	9.2	131
Minerals											
Calcium (mg)	1000	1073.5	107.4	1070.2	107	1064.1	106	1076.1	108	1077.8	108
Iodine (µg)	150	210.2	140.1	210.0	140	209.7	140	210.3	140	210.3	140
Iron (mg)	18	12.2	67.6	12.2	68	12.3	68	12.4	69	12.6	***70***
Magnesium (mg)	320	375.1	117.2	375.4	117	376.0	117	379.9	119	386.5	121
Phosphorus (mg)	1000	1715.2	171.5	1741.3	174	1792.7	179	1751.9	175	1817.5	182
Potassium (mg)	2800	3676.3	131.3	3734.5	133	3850.1	138	3809.0	136	4023.9	144
Selenium (µg)	60	75.2	125.4	80.1	133	89.5	149	80.2	134	89.7	150
Sodium (mg)	2300	1404.9	61.1	1206.4	52	1205.7	52	1210.8	53	1215.9	53
Zinc (mg)	8	13.8	172.1	13.7	172	13.7	171	13.8	173	13.9	173

[1] Vitamin D and any other nutrients notably affected by mushroom modelling shown italicised and in bold.

[2] Mushroom serves substituted for serves of "other vegetables".

[3] Mushroom serves added to existing serves of "other vegetables".

AI, adequate intake; DFE, dietary folate equivalents; excl, excluding; g, grams; kJ, kilojoules; LCn-3, long chain omega-3 fatty acids; incl, including; µg, micrograms; mg, milligrams; MUFA, monounsaturated fatty acids; N, number of serves; NRV, nutrient reference value; PUFA, polyunsaturated fatty acids; RDI, recommended daily intake; RE, retinol equivalents; SFA, saturated fatty acids.

Table A8. Women 19-30 years Ovo-Lacto Vegetarian diet

NUTRIENT[1]	NRV (RDI/ AI)	OVO-LACTO VEGETARIAN FOUNDATION DIET		SUB[2]. N=3 SERVES/WEEK		SUB[2]. N=7 SERVES/WEEK		ADD[3]. N=3 SERVES/WEEK		ADD[3]. N=7 SERVES/WEEK		ADD[3]. N=13 SERVES/WEEK	
		/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV
Macronutrients													
Energy, excl. fibre (kJ)	*NA*	6764.9	*NA*	6669.1	*NA*	6667.2	*NA*	6709.5	*NA*	6761.6	*NA*	6839.7	*NA*
Energy, incl, fibre (kJ)	7100	7144.6	101	7062.6	99	7061.0	99	7097.2	100	7141.8	101	7208.7	102
Protein (g)	46	88.2	192	87.6	191	88.4	192	88.0	191	89.4	194	91.4	199
Carbohydrate, total (g)	*NA*	186.3	*NA*	183.2	*NA*	182.4	*NA*	184.3	*NA*	185.1	*NA*	186.2	*NA*
Sugars, total (g)	44	70.8	161	67.7	154	66.4	151	68.8	156	68.8	156	68.8	156
Starch (g)	*NA*	114.8	*NA*	114.3	*NA*	114.2	*NA*	114.5	*NA*	114.5	*NA*	114.5	*NA*
Dietary fibre (g)	25	48.5	194	46.7	187	46.6	186	47.5	190	48.3	193	49.5	198
Fat, total (g)	66	57.8	88	57.2	87	57.1	87	57.4	87	57.7	87	58.0	88
SFA, total (g)	19	14.2	75	14.1	74	14.1	74	14.1	74	14.2	75	14.3	75
MUFA, total (g)	24	21.9	91	21.5	90	21.4	89	21.7	90	21.7	90	21.7	90
PUFA, total (g)	24	17.2	71	17.1	71	17.2	72	17.2	71	17.3	72	17.5	73
Linoleic acid (g)	8	16.1	202	16.1	202	16.2	203	16.1	202	16.3	204	16.5	206
Alpha linolenic acid (g)	0.8	1.0	123	1.0	123	1.0	123	1.0	123	1.0	123	1.0	123
LCn-3, total (mg)	90	49.5	55	49.5	55	49.5	55	49.5	55	49.5	55	49.5	55
Cholesterol (mg)	*NA*	227.9	*NA*	227.9	*NA*	227.9	*NA*	227.9	*NA*	227.9	*NA*	227.9	*NA*
Vitamins													
Thiamin (mg)	1.1	2.1	193	2.1	192	2.1	195	2.1	192	2.2	195	2.2	200
Riboflavin (mg)	1.1	2.4	215	2.3	213	2.3	213	2.4	214	2.4	214	2.4	214
Niacin equivalents (mg)	14	43.8	313	44.4	317	46.4	331	44.6	318	46.9	335	50.3	359
Vitamin B6 (mg)	1.3	1.7	127	1.6	120	1.5	117	1.6	123	1.6	123	1.6	124
Folate (DFE) (µg)	400	682.4	171	660.5	165	659.2	165	669.6	167	680.3	170	696.3	174
Folic acid (µg)	*NA*	924.4	*NA*	924.4	*NA*	924.4	*NA*	924.4	*NA*	924.4	*NA*	924.4	*NA*
Vitamin B12 (µg)	2.4	3.4	141	3.4	141	3.4	141	3.4	141	3.4	141	3.4	141
Vitamin A (RE) (µg)	700	1172.1	167	1126.4	161	1106.2	158	1141.5	163	1141.5	163	1141.5	163

NUTRIENT[1]	NRV (RDI/ AI)	OVO-LACTO VEGETARIAN FOUNDATION DIET		SUB[2]. N=3 SERVES/WEEK		SUB[2]. N=7 SERVES/WEEK		ADD[3]. N=3 SERVES/WEEK		ADD[3]. N=7 SERVES/WEEK		ADD[3]. N=13 SERVES/WEEK	
		/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV
Preformed retinol (µg)	*NA*	202.0	*NA*	202.0	*NA*	202.0	*NA*	202.0	*NA*	202.0	*NA*	202.0	*NA*
Provitamin A (µg)	*NA*	5821.4	*NA*	5547.5	*NA*	5426.9	*NA*	5637.9	*NA*	5637.9	*NA*	5637.9	*NA*
Vitamin C (mg)	45	83.3	185	52.5	117	39.0	87	62.6	139	62.6	139	62.6	139
Vitamin D (µg)	***5***	***1.5***	***30***	***2.1***	***42***	***3.3***	***66***	***2.1***	***42***	***3.3***	***66***	***5.1***	***102***
Vitamin E (mg)	7	11.0	158	10.6	151	10.4	148	10.7	153	10.7	153	10.7	153
Minerals													
Calcium (mg)	1000	1041.0	104	1024.0	102	1017.9	102	1029.8	103	1031.6	103	1034.1	103
Iodine (µg)	150	173.4	116	172.6	115	172.3	115	172.9	115	172.9	115	172.9	115
Iron (mg)	***18***	***17.1***	***95***	***16.8***	***93***	***16.9***	***94***	***16.9***	***94***	***17.2***	***96***	***17.6***	***98***
Magnesium (mg)	320	542.4	170	532.1	166	532.7	166	536.6	168	543.2	170	553.2	173
Phosphorus (mg)	1000	1793.0	179	1794.2	179	1845.6	185	1804.9	180	1870.5	187	1968.8	197
Potassium (mg)	2800	3520.7	126	3404.9	122	3520.5	126	3479.4	124	3694.4	132	4016.8	143
Selenium (µg)	***60***	***58.0***	***97***	***62.6***	***104***	***72.0***	***120***	***62.7***	***104***	***72.3***	***120***	***86.6***	***144***
Sodium (mg)	2300	1187.6	52	978.9	43	978.2	43	983.2	43	988.4	43	996.1	43
Zinc (mg)	8	12.3	154	12.1	152	12.1	151	12.2	153	12.2	153	12.3	154

[1] Vitamin D and any other nutrients notably affected by mushroom modelling shown italicised and in bold.

[2] Mushroom serves substituted for serves of “other vegetables”.

[3] Mushroom serves added to existing serves of “other vegetables”.

AI, adequate intake; DFE, dietary folate equivalents; excl, excluding; g, grams; kJ, kilojoules; LCn-3, long chain omega-3 fatty acids; incl, including; µg, micrograms; mg, milligrams; MUFA, monounsaturated fatty acids; N, number of serves; NRV, nutrient reference value; PUFA, polyunsaturated fatty acids; RDI, recommended daily intake; RE, retinol equivalents; SFA, saturated fatty acids.

Table A9. Men 51-70 years Omnivore diet

NUTRIENT[1]	NRV (RDI/ AI)	OMNIVORE FOUNDATION DIET		SUB[2]. N=3 SERVES/WEEK		SUB[2]. N=7 SERVES/WEEK		ADD[3]. N=3 SERVES/WEEK		ADD[3]. N=7 SERVES/WEEK		ADD[3]. N=19 SERVES/WEEK	
		/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV
Macronutrients													
Energy, excl. fibre (kJ)	*NA*	8020.2	*NA*	8021.0	*NA*	8022.8	*NA*	8058.7	*NA*	8110.7	*NA*	8266.9	*NA*
Energy, incl, fibre (kJ)	8200	8286.5	101	8287.3	101	8289.0	101	8319.4	101	8364.0	102	8497.7	***104***
Protein (g)	64	104.9	164	105.4	165	106.2	166	105.8	165	107.1	167	111.1	174
Carbohydrate, total (g)	*NA*	214.8	*NA*	214.3	*NA*	213.4	*NA*	215.6	*NA*	216.3	*NA*	218.6	*NA*
Sugars, total (g)	50	91.9	184	91.1	182	89.7	179	92.2	184	92.2	184	92.2	184
Starch (g)	*NA*	121.4	*NA*	121.3	*NA*	121.1	*NA*	121.4	*NA*	121.4	*NA*	121.4	*NA*
Dietary fibre (g)	30	34.4	115	34.4	115	34.3	114	35.1	117	35.9	120	38.4	128
Fat, total (g)	76	70.9	93	70.9	93	71.0	93	71.0	93	71.3	94	72.0	95
SFA, total (g)	22	21.9	100	22.0	100	22.0	100	22.0	100	22.0	100	22.2	101
MUFA, total (g)	27	23.5	87	23.4	87	23.3	86	23.5	87	23.5	87	23.5	87
PUFA, total (g)	27	20.3	75	20.4	76	20.5	76	20.4	76	20.6	76	21.0	78
Linoleic acid (g)	13	18.7	144	18.7	144	18.8	145	18.7	144	18.9	145	19.3	148
Alpha linolenic acid (g)	1.3	1.3	97	1.3	97	1.3	97	1.3	97	1.3	97	1.3	97
LCn-3, total (mg)	160	291.0	182	291.0	182	291.0	182	291.0	182	291.0	182	291.0	182
Cholesterol (mg)	*NA*	240.3	*NA*	240.3	*NA*	240.3	*NA*	240.3	*NA*	240.3	*NA*	240.3	*NA*
Vitamins													
Thiamin (mg)	1.2	1.6	134	1.6	136	1.7	138	1.6	136	1.7	139	1.8	148
Riboflavin (mg)	1.3	2.5	191	2.5	190	2.5	190	2.5	191	2.5	191	2.5	191
Niacin equivalents (mg)	16	51.8	324	53.0	331	55.0	344	53.2	332	55.4	347	62.3	389
Vitamin B6 (mg)	1.7	1.8	106	1.8	106	1.8	104	1.8	108	1.8	108	1.9	109
Folate (DFE) (µg)	400	494.7	124	494.4	124	494.1	124	502.7	126	513.5	128	545.6	136
Folic acid (µg)	N/A	741.4	*NA*	741.4	*NA*	741.4	*NA*	741.4	*NA*	741.4	*NA*	741.4	*NA*
Vitamin B12 (µg)	2.4	6.2	260	6.2	260	6.2	260	6.2	260	6.2	260	6.2	260
Vitamin A (RE) (µg)	900	1575.8	175	1566.1	174	1549.2	172	1578.8	175	1578.8	175	1578.8	175

NUTRIENT[1]	NRV (RDI/ AI)	OMNIVORE FOUNDATION DIET		SUB[2]. N=3 SERVES/WEEK		SUB[2]. N=7 SERVES/WEEK		ADD[3]. N=3 SERVES/WEEK		ADD[3]. N=7 SERVES/WEEK		ADD[3]. N=19 SERVES/WEEK	
		/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV
Preformed retinol (µg)	N/A	521.2	*NA*	521.2	*NA*	521.2	*NA*	521.2	*NA*	521.2	*NA*	521.2	*NA*
Provitamin A (µg)	N/A	6340.2	*NA*	6282.1	*NA*	6181.0	*NA*	6358.0	*NA*	6358.0	*NA*	6358.0	*NA*
Vitamin C (mg)	45	129.2	287	122.4	272	110.5	245	131.4	292	131.4	292	131.4	292
Vitamin D (µg)	***10***	***4.6***	***46***	***5.3***	***53***	***6.5***	***65***	***5.3***	***53***	***6.5***	***65***	***10.1***	***101***
Vitamin E (mg)	10	12.8	128	12.7	127	12.6	126	12.8	128	12.8	128	12.8	128
Minerals													
Calcium (mg)	1000	1120.9	112	1117.1	112	1110.7	111	1123.2	112	1125.0	112	1130.1	113
Iodine (µg)	150	219.1	146	218.9	146	218.7	146	219.1	146	219.1	146	219.1	146
Iron (mg)	8	12.3	154	12.3	154	12.4	155	12.5	156	12.8	159	13.6	169
Magnesium (mg)	420	392.3	93	392.7	94	393.4	94	397.1	95	403.8	96	423.7	***101***
Phosphorus (mg)	1000	1801.8	180	1831.1	183	1882.4	188	1841.8	184	1907.3	191	2104.0	210
Potassium (mg)	3800	3907.9	103	3973.1	105	4087.4	108	4048.5	107	4263.5	112	4908.3	129
Selenium (µg)	70	81.4	116	86.8	124	96.3	138	86.9	124	96.5	138	125.2	179
Sodium (mg)	2300	1501.9	65	1501.0	65	1499.3	65	1506.1	65	1511.2	66	1526.6	66
Zinc (mg)	14	14.1	101	14.1	101	14.0	100	14.1	101	14.2	101	14.3	102

[1] Vitamin D and any other nutrients notably affected by mushroom modelling shown italicised and in bold.

[2] Mushroom serves substituted for serves of “other vegetables”.

[3] Mushroom serves added to existing serves of “other vegetables”.

AI, adequate intake; DFE, dietary folate equivalents; excl, excluding; g, grams; kJ, kilojoules; LCn-3, long chain omega-3 fatty acids; incl, including; µg, micrograms; mg, milligrams; MUFA, monounsaturated fatty acids; N, number of serves; NRV, nutrient reference value; PUFA, polyunsaturated fatty acids; RDI, recommended daily intake; RE, retinol equivalents; SFA, saturated fatty acids.

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Table A10. Men 51-70 years Ovo-Lacto Vegetarian diet

NUTRIENT[1]	NRV (RDI/ AI)	OVO-LACTO VEGETARIAN FOUNDATION DIET		SUB[2]. N=3 SERVES/WEEK		SUB[2]. N=7 SERVES/WEEK		ADD[3]. N=3 SERVES/WEEK		ADD[3]. N=7 SERVES/WEEK		ADD[3]. N=27 SERVES/WEEK	
		/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV
Macronutrients													
Energy, excl. fibre (kJ)	*NA*	7647.8	*NA*	7560.7	*NA*	7562.5	*NA*	7598.4	*NA*	7650.4	*NA*	7910.8	*NA*
Energy, incl, fibre (kJ)	8200	8043.3	98	7969.1	97	7970.8	97	8001.2	98	8045.8	98	8268.7	101
Protein (g)	64	91.7	143	91.3	143	92.1	144	91.7	143	93.0	145	99.6	156
Carbohydrate, total (g)	*NA*	211.9	*NA*	208.5	*NA*	207.6	*NA*	209.7	*NA*	210.5	*NA*	214.4	*NA*
Sugars, total (g)	50	94.3	189	91.0	182	89.6	179	92.0	184	92.0	184	92.0	184
Starch (g)	*NA*	116.1	*NA*	115.6	*NA*	115.4	*NA*	115.8	*NA*	115.8	*NA*	115.8	*NA*
Dietary fibre (g)	30	50.5	168	48.9	163	48.8	163	49.5	165	50.4	168	54.6	182
Fat, total (g)	76	68.3	90	68.1	90	68.1	90	68.2	90	68.4	90	69.6	92
SFA, total (g)	22	17.6	80	17.6	80	17.6	80	17.6	80	17.6	80	17.9	81
MUFA, total (g)	27	25.7	95	25.5	94	25.4	94	25.6	95	25.6	95	25.6	95
PUFA, total (g)	27	20.2	75	20.2	75	20.3	75	20.2	75	20.4	75	21.0	78
Linoleic acid (g)	13	19.1	147	19.1	147	19.2	148	19.1	147	19.3	148	19.9	153
Alpha linolenic acid (g)	1.3	1.1	85	1.1	85	1.1	85	1.1	85	1.1	85	1.1	85
LCn-3, total (mg)	160	39.3	25	39.3	25	39.3	25	39.3	25	39.3	25	39.3	25
Cholesterol (mg)	*NA*	182.4	*NA*	182.4	*NA*	182.4	*NA*	182.4	*NA*	182.4	*NA*	182.4	*NA*
Vitamins													
Thiamin (mg)	1.2	2.1	178	2.2	179	2.2	182	2.2	180	2.2	183	2.4	197
Riboflavin (mg)	1.3	2.5	192	2.5	190	2.5	190	2.5	191	2.5	191	2.5	191
Niacin equivalents (mg)	16	46.8	293	47.6	297	49.6	310	47.7	298	50.0	313	61.4	384
Vitamin B6 (mg)	1.7	2.0	116	1.9	112	1.9	110	1.9	114	1.9	114	2.0	116
Folate (DFE) (µg)	400	703.6	176	684.0	171	683.6	171	692.3	173	703.0	176	756.6	189
Folic acid (µg)	*NA*	958.7	*NA*	958.7	*NA*	958.7	*NA*	958.7	*NA*	958.7	*NA*	958.7	*NA*
Vitamin B12 (µg)	2.4	3.7	156	3.7	156	3.7	156	3.7	156	3.7	156	3.7	156
Vitamin A (RE) (µg)	900	1324.3	147	1285.1	143	1268.2	141	1297.7	144	1297.7	144	1297.7	144

NUTRIENT[1]	NRV (RDI/ AI)	OVO-LACTO VEGETARIAN FOUNDATION DIET		SUB[2]. N=3 SERVES/WEEK		SUB[2]. N=7 SERVES/WEEK		ADD[3]. N=3 SERVES/WEEK		ADD[3]. N=7 SERVES/WEEK		ADD[3]. N=27 SERVES/WEEK	
		/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV
Preformed retinol (µg)	*NA*	291.3	*NA*	291.3	*NA*	291.3	*NA*	291.3	*NA*	291.3	*NA*	291.3	*NA*
Provitamin A (µg)	*NA*	6204.7	*NA*	5969.6	*NA*	5868.5	*NA*	6045.5	*NA*	6045.5	*NA*	6045.5	*NA*
Vitamin C (mg)	45	128.9	287	101.3	225	89.3	198	110.3	245	110.3	245	110.3	245
Vitamin D (µg)	***10***	***2.2***	***22***	***2.9***	***29***	***4.1***	***41***	***2.9***	***29***	***4.1***	***41***	***10.1***	***101***
Vitamin E (mg)	10	13.4	134	13.0	130	12.9	129	13.1	131	13.1	131	13.1	131
Minerals													
Calcium (mg)	1000	1195.9	120	1177.9	118	1171.4	117	1184.0	118	1185.7	119	1194.3	119
Iodine (µg)	150	198.5	132	197.9	132	197.6	132	198.1	132	198.1	132	198.1	132
Iron (mg)	8	16.1	202	15.8	198	15.9	199	16.0	200	16.2	203	17.6	220
Magnesium (mg)	420	559.0	133	549.0	131	549.7	131	553.4	132	560.1	133	593.3	141
Phosphorus (mg)	1000	1915.1	192	1919.5	192	1970.8	197	1930.2	193	1995.7	200	2323.6	232
Potassium (mg)	3800	4246.0	112	4135.1	109	4249.4	112	4210.6	111	4425.5	116	5500.2	145
Selenium (µg)	***70***	***65.4***	***93***	***70.5***	***101***	***80.0***	***114***	***70.6***	***101***	***80.2***	***115***	***128.0***	***183***
Sodium (mg)	2300	1341.9	58	1329.0	58	1327.3	58	1334.1	58	1339.3	58	1365.0	59
Zinc (mg)	***14***	***12.7***	***91***	***12.5***	***89***	***12.4***	***89***	***12.5***	***90***	***12.6***	***90***	***12.7***	***91***

[1] Vitamin D and any other nutrients notably affected by mushroom modelling shown italicised and in bold.

[2] Mushroom serves substituted for serves of "other vegetables".

[3] Mushroom serves added to existing serves of "other vegetables".

AI, adequate intake; DFE, dietary folate equivalents; excl, excluding; g, grams; kJ, kilojoules; LCn-3, long chain omega-3 fatty acids; incl, including; µg, micrograms; mg, milligrams; MUFA, monounsaturated fatty acids; N, number of serves; NRV, nutrient reference value; PUFA, polyunsaturated fatty acids; RDI, recommended daily intake; RE, retinol equivalents; SFA, saturated fatty acids.

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Table A11. Women 70+ years Omnivore diet

NUTRIENT[1]	NRV (RDI/ AI)	OMNIVORE FOUNDATION DIET		SUB[2]. N=3 SERVES/WEEK		SUB[2]. N=7 SERVES/WEEK		ADD[3]. N=3 SERVES/WEEK		ADD[3]. N=7 SERVES/WEEK		ADD[3]. N=36 SERVES/WEEK	
		/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV
Macronutrients													
Energy, excl. fibre (kJ)	*NA*	6380.5	*NA*	6380.5	*NA*	6379.9	*NA*	6420.1	*NA*	6472.2	*NA*	6849.7	*NA*
Energy, incl, fibre (kJ)	6500	6586.6	101.3	6586.9	101	6586.6	101	6620.5	102	6665.1	103	6988.2	108
Protein (g)	57	94.1	165.1	94.6	166	95.4	167	95.0	167	96.3	169	106.0	186
Carbohydrate, total (g)	*NA*	169.5	*NA*	168.9	*NA*	168.1	*NA*	170.2	*NA*	170.9	*NA*	176.5	*NA*
Sugars, total (g)	40	108.2	270.6	107.3	268	105.9	265	108.4	271	108.4	271	108.4	271
Starch (g)	*NA*	59.6	*NA*	59.5	*NA*	59.3	*NA*	59.7	*NA*	59.7	*NA*	59.7	*NA*
Dietary fibre (g)	25	26.0	104.0	25.9	104	25.8	103	26.6	107	27.5	110	33.5	134
Fat, total (g)	60	52.6	87.6	52.6	88	52.6	88	52.7	88	53.0	88	54.7	91
SFA, total (g)	17	19.1	112.4	19.1	112	19.1	113	19.1	113	19.2	113	19.5	115
MUFA, total (g)	22	17.2	78.4	17.1	78	17.0	77	17.2	78	17.3	78	17.3	79
PUFA, total (g)	22	12.1	55.0	12.2	55	12.3	56	12.2	55	12.3	56	13.3	60
Linoleic acid (g)	8	11.0	137.4	11.1	138	11.2	140	11.1	139	11.2	140	12.2	152
Alpha linolenic acid (g)	0.8	0.8	101.3	0.8	101	0.8	101	0.8	101	0.8	101	0.8	101
LCn-3, total (mg)	90	329.4	366.0	329.4	366	329.4	366	329.4	366	329.4	366	329.4	366
Cholesterol (mg)	*NA*	239.9	*NA*	239.9	*NA*	239.9	*NA*	239.9	*NA*	239.9	*NA*	239.9	*NA*
Vitamins													
Thiamin (mg)	1.1	1.0	92.7	1.0	95	1.1	97	1.0	95	1.1	98	1.3	121
Riboflavin (mg)	1.3	2.9	223.1	2.9	223	2.9	222	2.9	223	2.9	223	2.9	223
Niacin equivalents (mg)	14	45.8	326.9	47.1	337	49.2	351	47.3	338	49.6	354	66.1	472
Vitamin B6 (mg)	1.5	1.7	111.3	1.6	110	1.6	108	1.7	112	1.7	112	1.7	115
Folate (DFE) (µg)	400	512.9	128.2	512.8	128	512.5	128	521.1	130	531.8	133	609.5	152
Folic acid (µg)	*NA*	641.1	*NA*	641.1	*NA*	641.1	*NA*	641.1	*NA*	641.1	*NA*	641.1	*NA*
Vitamin B12 (µg)	2.4	8.1	337.9	8.1	338	8.1	338	8.1	338	8.1	338	8.1	338
Vitamin A (RE) (µg)	700	1366.6	195.2	1355.7	194	1339.1	191	1368.2	195	1368.2	195	1368.2	195

NUTRIENT[1]	NRV (RDI/ AI)	OMNIVORE FOUNDATION DIET		SUB[2]. N=3 SERVES/WEEK		SUB[2]. N=7 SERVES/WEEK		ADD[3]. N=3 SERVES/WEEK		ADD[3]. N=7 SERVES/WEEK		ADD[3]. N=36 SERVES/WEEK	
		/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV
Preformed retinol (μg)	*NA*	433.5	*NA*	433.5	*NA*	433.5	*NA*	433.5	*NA*	433.5	*NA*	433.5	*NA*
Provitamin A (μg)	*NA*	5617.2	*NA*	5552.3	*NA*	5452.7	*NA*	5627.1	*NA*	5627.1	*NA*	5627.1	*NA*
Vitamin C (mg)	45	122.4	271.9	116.0	258	106.1	236	123.4	274	123.4	274	123.4	274
Vitamin D (μg)	***15***	***4.5***	***29.9***	***5.3***	***35***	***6.5***	***43***	***5.3***	***35***	***6.5***	***43***	***15.1***	***101***
Vitamin E (mg)	7	8.7	124.3	8.6	123	8.5	121	8.7	124	8.7	124	8.7	124
Minerals													
Calcium (mg)	1300	1397.7	107.5	1392.6	107	1384.7	107	1399.9	108	1401.6	108	1414.0	109
Iodine (μg)	150	260.3	173.5	260.2	173	260.0	173	260.3	174	260.3	174	260.3	174
Iron (mg)	8	8.6	106.9	8.6	108	8.7	109	8.8	109	9.0	113	11.0	137
Magnesium (mg)	320	347.0	108.4	347.2	108	347.4	109	352.0	110	358.6	112	406.8	127
Phosphorus (mg)	1000	1776.6	177.7	1810.4	181	1861.6	186	1821.3	182	1886.9	189	2362.2	236
Potassium (mg)	2800	3845.6	137.3	3919.3	140	4029.7	144	3997.7	143	4212.6	150	5770.9	206
Selenium (μg)	60	64.8	108.0	71.0	118	80.4	134	71.1	119	80.7	134	150.0	250
Sodium (mg)	2300	1178.5	51.2	1177.2	51	1175.2	51	1182.5	51	1187.7	52	1224.9	53
Zinc (mg)	8	11.9	148.9	11.9	149	11.8	148	12.0	149	12.0	150	12.2	153

[1] Vitamin D and any other nutrients notably affected by mushroom modelling shown italicised and in bold.

[2] Mushroom serves substituted for serves of “other vegetables”.

[3] Mushroom serves added to existing serves of “other vegetables”.

AI, adequate intake; DFE, dietary folate equivalents; excl, excluding; g, grams; kJ, kilojoules; LCn-3, long chain omega-3 fatty acids; incl, including; μg, micrograms; mg, milligrams; MUFA, monounsaturated fatty acids; N, number of serves; NRV, nutrient reference value; PUFA, polyunsaturated fatty acids; RDI, recommended daily intake; RE, retinol equivalents; SFA, saturated fatty acids.

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Table A12. Women 70+ years Ovo-Lacto Vegetarian diet

NUTRIENT[1]	NRV (RDI/ AI)	OVO-LACTO VEGETARIAN FOUNDATION DIET		SUB[2]. N=3 SERVES/WEEK		SUB[2]. N=7 SERVES/WEEK		ADD[3]. N=3 SERVES/WEEK		ADD[3]. N=7 SERVES/WEEK		ADD[3]. N=27 SERVES/WEEK	
		/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV
Macronutrients													
Energy, excl. fibre (kJ)	*NA*	6095.5	*NA*	6003.3	*NA*	6002.6	*NA*	6042.8	*NA*	6094.9	*NA*	6576.5	*NA*
Energy, incl, fibre (kJ)	6500	6391.6	98.3	6313.4	97	6313.1	97	6347.0	98	6391.6	98	6803.9	105
Protein (g)	57	85.4	149.8	85.0	149	85.8	151	85.4	150	86.7	152	99.0	174
Carbohydrate, total (g)	*NA*	162.3	*NA*	158.9	*NA*	158.0	*NA*	160.1	*NA*	160.9	*NA*	168.0	*NA*
Sugars, total (g)	40	83.1	207.9	79.8	199	78.3	196	80.8	202	80.8	202	80.8	202
Starch (g)	*NA*	78.2	*NA*	77.8	*NA*	77.6	*NA*	77.9	*NA*	77.9	*NA*	77.9	*NA*
Dietary fibre (g)	25	37.3	149.2	35.5	142	35.4	141	36.2	145	37.1	148	44.8	179
Fat, total (g)	60	52.0	86.6	51.6	86	51.6	86	51.8	86	52.0	87	54.2	90
SFA, total (g)	17	15.6	91.5	15.5	91	15.5	91	15.5	91	15.6	92	16.0	94
MUFA, total (g)	22	19.2	87.1	18.8	86	18.7	85	18.9	86	18.9	86	19.0	86
PUFA, total (g)	22	13.4	60.9	13.4	61	13.5	62	13.4	61	13.6	62	14.8	67
Linoleic acid (g)	8	12.6	157.9	12.7	158	12.8	160	12.7	159	12.8	160	14.1	176
Alpha linolenic acid (g)	0.8	0.8	103.8	0.8	104	0.8	104	0.8	104	0.8	104	0.8	104
LCn-3, total (mg)	90	39.4	43.7	39.4	44	39.4	44	39.4	44	39.4	44	39.4	44
Cholesterol (mg)	*NA*	194.5	*NA*	194.5	*NA*	194.5	*NA*	194.5	*NA*	194.5	*NA*	194.5	*NA*
Vitamins													
Thiamin (mg)	1.1	1.5	136.4	1.5	137	1.5	140	1.5	138	1.6	141	1.9	170
Riboflavin (mg)	1.3	2.6	198.5	2.6	197	2.6	197	2.6	198	2.6	198	2.6	198
Niacin equivalents (mg)	14	40.5	289.6	41.5	296	43.5	311	41.7	298	43.9	314	65.0	464
Vitamin B6 (mg)	1.5	1.5	100.0	1.4	95	1.4	93	1.4	96	1.5	97	1.5	100
Folate (DFE) (µg)	400	622.8	155.7	603.3	151	603.0	151	611.6	153	622.4	156	721.5	180
Folic acid (µg)	*NA*	785.8		785.8	*NA*	785.8	*NA*	785.8	*NA*	785.8	*NA*	785.8	*NA*
Vitamin B12 (µg)	2.4	5.3	220.8	5.3	221	5.3	221	5.3	221	5.3	221	5.3	221
Vitamin A (RE) (µg)	700	1080.1	154.3	1040.2	149	1023.5	146	1052.7	150	1052.7	150	1052.7	150

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NUTRIENT[1]	NRV (RDI/ AI)	OVO-LACTO VEGETARIAN FOUNDATION DIET		SUB[2]. N=3 SERVES/WEEK		SUB[2]. N=7 SERVES/WEEK		ADD[3]. N=3 SERVES/WEEK		ADD[3]. N=7 SERVES/WEEK		ADD[3]. N=27 SERVES/WEEK	
		/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV	/day	%NRV
Preformed retinol (µg)	*NA*	251.5	*NA*	251.5	*NA*	251.5	*NA*	251.5	*NA*	251.5	*NA*	251.5	*NA*
Provitamin A (µg)	*NA*	4980.5	*NA*	4741.3	*NA*	4641.6	*NA*	4816.0	*NA*	4816.0	*NA*	4816.0	*NA*
Vitamin C (mg)	45	83.6	185.8	59.9	133	50.0	111	67.3	150	67.3	150	67.3	150
Vitamin D (µg)	***15***	***2.1***	***14.1***	***2.9***	***19***	***4.1***	***27***	***2.9***	***19***	***4.1***	***27***	***15.1***	***101***
Vitamin E (mg)	7	8.7	123.9	8.4	119	8.2	118	8.5	121	8.5	121	8.5	121
Minerals													
Calcium (mg)	1300	1295.2	99.6	1273.2	98	1265.2	97	1280.4	98	1282.2	99	1298.0	100
Iodine (µg)	150	218.1	145.4	217.6	145	217.4	145	217.7	145	217.7	145	217.7	145
Iron (mg)	8	12.4	154.8	12.1	151	12.2	152	12.2	153	12.5	156	15.0	187
Magnesium (mg)	320	462.1	144.4	451.0	141	451.2	141	455.8	142	462.5	145	524.0	164
Phosphorus (mg)	1000	1787.2	178.7	1795.7	180	1846.8	185	1806.5	181	1872.1	187	2478.6	248
Potassium (mg)	2800	3598.7	128.5	3489.4	125	3599.8	129	3567.8	127	3782.7	135	5770.9	206
Selenium (µg)	***60***	***47.7***	***79.5***	***53.7***	***89***	***63.1***	***105***	***53.8***	***90***	***63.3***	***106***	***151.8***	***253***
Sodium (mg)	2300	1071.3	46.6	1057.6	46	1055.6	46	1062.9	46	1068.1	46	1115.6	49
Zinc (mg)	8	11.1	139.1	10.9	137	10.9	136	11.0	138	11.0	138	11.4	142

[1] Vitamin D and any other nutrients notably affected by mushroom modelling shown italicised and in bold.

[2] Mushroom serves substituted for serves of "other vegetables".

[3] Mushroom serves added to existing serves of "other vegetables".

AI, adequate intake; DFE, dietary folate equivalents; excl, excluding; g, grams; kJ, kilojoules; LCn-3, long chain omega-3 fatty acids; incl, including; µg, micrograms; mg, milligrams; MUFA, monounsaturated fatty acids; N, number of serves; NRV, nutrient reference value; PUFA, polyunsaturated fatty acids; RDI, recommended daily intake; RE, retinol equivalents; SFA, saturated fatty acids.

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Mushrooms in the Australian Dietary Guidelines: Submission support

Prepared for:

Australian Mushroom Growers Association

May 2023

Prepared by:

Nutrition Research Australia Pty Ltd

Background

The Australian Dietary Guidelines

The Australian Dietary Guidelines (ADG) are designed to provide up to date advice about the amounts and kinds of foods to eat for health and wellbeing, based on scientific evidence. The current (2013) guidelines are under review and due for update in 2025. Their progress can be followed here.

Mushrooms

There are over 2000 varieties of edible mushrooms [1]. The most frequently consumed mushrooms in Australia are:

- Common (*Agaricus bisporus* species) mushroom varieties, including:
  - White button, the most frequently consumed mushroom in Australia and worldwide,
  - Swiss brown,
  - Cup,
  - Flat, and
  - Portobello.
- Exotic mushroom varieties, including:
  - Oyster (Pleurotus ostreatus),
  - King oyster (Pleurotus eryngii),
  - Shiitake (Lentinula edodes),
  - Enoki (*Flammulina filformis*), and
  - Shimeji (*Hypsizygus tessellatus*).

In the current ADG, mushrooms are categorised in the 'vegetables and legumes/beans' food group. This food group is divided into five subcategories: 'dark green or cruciferous/brassica', 'orange vegetables', 'root/tubular/bulb', 'legumes/beans' and 'other vegetables'. Mushrooms are placed in the 'other vegetables' subcategory, which includes many of the salad vegetables such as tomato, beetroot, and cucumber.

The Brief

The Australian Mushroom Growers Association, on behalf of Hort Innovation, is advocating for the repositioning of mushrooms in the ADG and commissioned Nutrition Research Australia (NRAUS) to support with the strategic direction and collation of the scientific evidence and advocacy messages.

The project consists of three phases:

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Phase 1: Determine the best strategic pathways to help achieve repositioning in the updated 2025 ADG. This has been completed and a decision was made to advocate for mushrooms to be its own subcategory within a revamped ‘vegetable, legumes/beans, and mushrooms’ food group.

Phase 2: Collate the relevant evidence to support repositioning in the form of a scientific summary report. This has been completed and included dietary modelling to capture the nutritional impact that such a change would have on key population groups in Australia.

Phase 3: Translation of this science into key messages that will support the mushroom industry with making a submission to the ADG.

This report is **Phase 3**: translation of the science into key advocacy messages to support the industry.

Summary of Recommendations

Five recommendations have been put forward for the revision of the Australian Dietary Guidelines:

A. Adequately address low vitamin D intakes.

1. Change the wording of the current “Vegetables and legumes/beans” food group to, “Vegetables, mushrooms, and legumes/beans”.

2. “Mushrooms” to be an additional subcategory within the “Vegetables, mushrooms, and legumes/beans” food group.

3. Provide specific practical recommendations for enhancing the vitamin D content of mushrooms: buying vitamin D enriched mushrooms and/or putting mushrooms in sunlight (for 15 to 60 minutes).

B. Provide greater practical advice to lower sodium intake.

4. Provide specific practical recommendations for using foods high in umami and low in sodium, such as mushrooms, as a strategy for reducing sodium intake.

C. Provide greater practical advice to help relevant population groups to lower red meat intake without increasing ultra-processed or discretionary food consumption.

5. Provide specific practical recommendations to reduce red meat intake using mushrooms as a substitute, for relevant demographic groups.

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A. Adequately address low vitamin D intakes.

The current ADG are insufficient for helping people to meet their vitamin D needs. Strong leadership from the Australian Dietary Guidelines committee, with significant changes to the current guidelines, are required to address this urgent public health problem.

Scientific rationale:

- Almost 1 in 4 (23%) Australian adults have vitamin D deficiency.
- Current vitamin D intakes (1.84 – 3.25 µg/day) are well below Adequate Intake levels (5-15 µg/day).
- Australian vitamin D intakes are among the lowest reported globally.
- In dietary modelling to inform the current Australian Dietary Guidelines, vitamin D intakes are consistently below Adequate Intake levels.

Prevalence of vitamin D deficiency and insufficiency

Vitamin D deficiency is a significant public health problem in Australia. Evidence from large, nationally representative samples show that around 1 in 4 Australians are vitamin D deficient (serum 25-hydroxyvitamin D concentrations [25(OH)D] < 50 nmol/L [2, 3]):

- 4% of pre-school children [4],
- 17% of adolescents and 32% of young adults [5],
- 20% of adults aged 25 years and over [6],
- 16 to 20% of adults aged 65 years and over [7], and
- 27% of Australian Aboriginal and Torres Strait Islander adults [8].

A further 43% of adults [6] and 16% of pre-school children [4] are vitamin D insufficient (defined as serum [25(OH)D] 50-75 nmol/L [2, 3]).

Health risks of vitamin D deficiency and insufficiency

The high prevalence of vitamin D deficiency and insufficiency is concerning as it increases the risk for both infectious and non-communicable diseases:

- Vitamin D deficiency is well established to decrease calcium absorption and result in impaired bone health [9].
- Studies have linked vitamin D deficiency or insufficiency to increased susceptibility to infectious diseases (including COVID-19 and upper respiratory tract infection), muscle weakness, multiple sclerosis, diabetes, hypertension, metabolic syndrome, cancers, autoimmune diseases,

cardiovascular disease, and bone fracture in later life [10]. Vitamin D deficiency during pregnancy has also been associated with an increased risk for gestational diabetes [11].

- While sunlight is considered to be a primary source of vitamin D [3, 12], these data suggest that the majority of individuals (including Australians) do not produce sufficient vitamin D via this source. Limited sun exposure may be due to multiple reasons including working indoors, having dark skin, or specifically avoiding sunlight due to sensitivity.

Current intakes of vitamin D vs. recommended levels

Intakes of vitamin D in Australia are well below recommended levels. This is the case across all population groups:

- In a 2023 evaluation of the 2011-2013 Australian Health Survey, average intakes ranged from 1.84 to 3.25 µg/day for people 2 years or older [3].
- The Adequate Intake (AI) for vitamin D in Australia is 5 - 15 µg/day [13]:
    - **Infants and children:** 5 µg/day,
    - **Adults up to 50 years:** 5 µg/day,
    - **Adults 51-70 years:** 10 µg/day, and
    - **Adults over 70 years:** 15 µg/day.
- The Institute of Medicine in the US recommends an Estimated Average Requirements for vitamin D of 10 µg/day [14]. In a 2023 evaluation of the 2011-2013 Australian Health Survey, more than 95% had intakes <10 µg/day [3].
    - Not a single participant exceeded the Upper Level of Intake (63-100 µg/day).

Australia also has among the lowest estimated intakes of vitamin D globally:

- Global adult intakes are [15]:
    - **Australia:** between 1.84 to 3.25 µg/day,
    - **United States:** between 3.5 and 6 µg/day,
    - **Canada:** average of 5.8 µg/day,
    - **Europe:** between 2 to 4 µg/day, and
    - **Ireland:** up to 3.7 µg/day.

The elderly, pregnant women, and people from low to middle socioeconomic areas have been highlighted as particularly vulnerable groups, often with increased vitamin D needs [10, 16, 17]. Vegetarians and vegans may also have greater difficulty meeting vitamin D needs due to their restricted intake of animal foods [15].

How current dietary guidelines address low vitamin D intakes

Diets produced during modelling to inform the ADG consistently do not meet the Adequate Intake values for vitamin D [12]. Vitamin D was the **only** nutrient that did not consistently meet the Nutrient Reference Value in the modelling to inform the ADG [12].

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Recent dietary modelling in Australia [18] showed that the fortification of milk with vitamin D (0.8 µg/100 mL milk; the maximum permitted level) would increase vitamin D intake to 4.9 µg/day. This is a meaningful increase but still below dietary targets. Previous Australian dietary modelling conducted in 2013 [19] estimated that if all milk and breakfast cereals were to be fortified with vitamin D (1 µg/100 mL in milk, and 3.5 µg/100 g in breakfast cereals), the average intake of vitamin D from foods would increase to 6.3 µg/day. This increase would allow vitamin D Adequate Intakes to be met for adults up to 50 years of age [13], although this level of fortification for milk is more than the amount currently permitted in Australia [19, 20] and breakfast cereals that do not meet the Nutrient Profiling Scoring Criteria and are currently not permitted to be fortified with vitamin D [21].

In modelling to inform the US Dietary Guidelines, several hypothetical models were explored to meet vitamin D needs [22]. The only option that brought vitamin D intake to the recommended level encouraged seafood choices with the highest quantities of vitamin D, fortification of both dairy and juice, and the potential fortification of grain products. However, even in this model, it was unrealistic as seafood choices were limited to those not normally consumed.

Recommendation 1: Change the wording of the current "Vegetables and legumes/beans" food group to, "Vegetables, mushrooms, and legumes/beans".

Scientific rationale:

Will help to address low vitamin D intakes:

- All vegetables have a vitamin D content of 0 µg.
- Mushrooms are not vegetables. They belong to a separate biological kingdom, fungi.
- Mushrooms are a source of vitamin D (1.6 µg/75 grams) and vitamin D is a 'distinguishing' nutrient for mushrooms.
- As the only natural, vegan source of vitamin D, they are likely to have a critical role for increasing vitamin D intakes in vegetarian and vegan diets.

In addition:

- Mushrooms are nutritionally distinct to vegetables and bring a different package of characterising nutrients not commonly found in vegetables in addition to vitamin D, including niacin, vitamin B5, biotin, copper, phosphorus, and selenium.
- Because the nutritional value of mushrooms is different to all vegetables, separating mushrooms from vegetables will stop factually incorrect statements that are currently being made in dietary guidelines (e.g. vegetables are a source of vitamin C) when mushrooms are classified as vegetables, that may be causing unintended harm.

The biological classification of mushrooms

While mushrooms are currently classified as vegetables, in biological terms, mushrooms are not vegetables. They belong to the third eukaryotic biological kingdom of fungi, separate to both the animal and plant kingdoms. When viewed in terms of evolutionary relationships and genetic similarity, mushrooms share a more recent common ancestor with animals compared to plants [23, 24]. These relationships are depicted in the phylogenetic tree in **Figure 1**.

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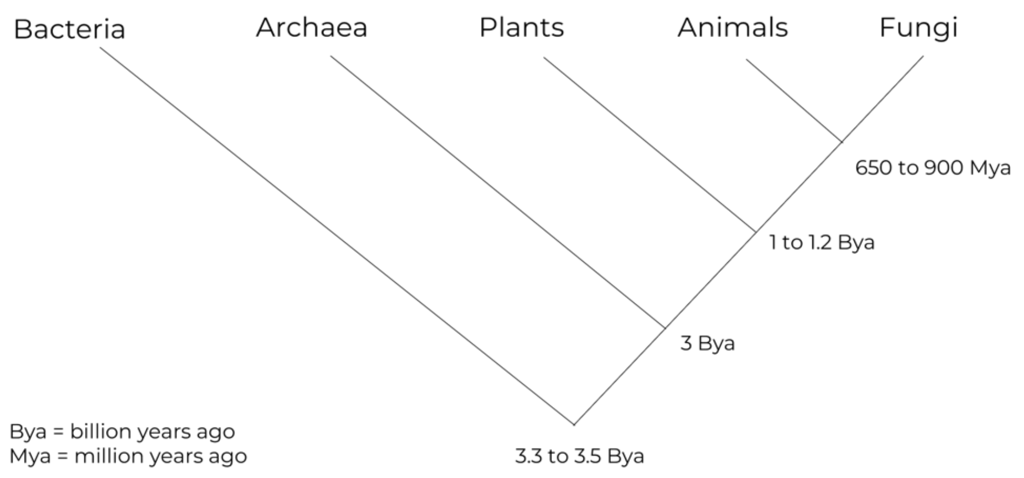

Figure 1. Phylogenetic tree showing the five kingdoms and their relationship, adapted from [25].

The vitamin D content of mushrooms

All vegetables have a vitamin D content of 0 µg. They cannot increase vitamin D intake. In contrast, mushrooms are a source of vitamin D (1.6 µg D_2/75 grams; 16% RDI) [26]. This is because mushrooms contain the unique sterol, ergosterol, that is a precursor to vitamin D_2 and not present in plants [1]. This makes vitamin D a key or 'distinguishing' nutrient for mushrooms, distinct from all other vegetables.

Mushrooms are the only natural, vegan source of vitamin D in the diet [15]. They have an important role in addressing low vitamin D intakes and this role is likely to be particularly critical for vegetarian and vegan diets.

The composition of other nutrients in mushrooms vs. vegetables

While vegetables are characterised by a particular set of nutrients, mushrooms provide a unique array of nutrients that is dissimilar from all other food categories, including vegetables, grains, and meats [1, 26, 27].

Per 100 grams, mushrooms (white button, raw) provide more than 10% of the recommended daily intake (RDI) or the estimated safe and adequate daily dietary intake (ESADDI) [28, 29] of other vitamins and minerals [26] (in addition to vitamin D): niacin (3.8 mg, 38% of RDI), biotin (8.5 mg, 28% of ESADDI), vitamin B5 (1.2 mg, 24% of ESSADI), selenium (16 µg, 23% of RDI), copper (0.37 mg, 12% of ESSADI), phosphorus (110 mg, 11% of RDI), folate (22 µg, 11% of RDI), and potassium (360 mg).

The comparison between the nutrients in mushrooms and the key or 'distinguishing' nutrients in vegetables is shown in **Table 2**. Potassium and folate are the only characterising nutrients in common to both mushrooms and the vegetables food group. Mushrooms provide additional micronutrients not common in most vegetables, including vitamin D, niacin, vitamin B5, biotin, copper, phosphorus, and selenium.

Table 2. Comparison of the key nutrients provided by mushrooms and vegetables (including legumes).

MUSHROOMS[1] (WHITE BUTTON)	VEGETABLES[2] (INCLUDING LEGUMES)
Niacin	Carbohydrate
Vitamin B5	Dietary fibre
Biotin	Pro-vitamin A
Folate	**Folate**
Vitamin D	Vitamin C
Copper	Iron
Phosphorus	Magnesium
Potassium	**Potassium**
Selenium	

Nutrients shared by both mushrooms and vegetables are shown in bold.

[1] At least 10% of daily requirement based on nutritional composition per 100 g [26, 28, 29].

[2] Characterising nutrients of the vegetables and legumes/beans core food group within the ADG [27].

Mushrooms are also not a source of some key nutrients present in vegetables, such as vitamin C. Current statements in the Australian Dietary Guidelines, e.g., "Vegetables are a source of vitamin C" are therefore factually incorrect when mushrooms are categorised as a vegetable. This may be misleading and have unintended consequences, e.g., health educators incorrectly recommending increased consumption of mushrooms to increase vitamin C intake.

Recommendation 2: "Mushrooms" to be an additional subcategory within the "Vegetables, mushrooms, and legumes/beans" food group.

Scientific rationale:

Will help to address low vitamin D intakes:

- In dietary modelling, the addition of "mushrooms" as a subcategory within the current "vegetables and legumes/beans" food group improves vitamin D intake.

In addition:

- It will increase the intake of other micronutrients, including selenium, an at-risk nutrient in vegetarian diets.
- It will increase bioactive diversity. The bioactives present in mushrooms, including ergothioneine, beta-glucan, chitin, and phytosterols, are often low or absent in vegetables and have important health properties, such as prebiotic and cholesterol-lowering.
- No significant adverse impacts on energy or micronutrient intake with the addition of "mushrooms" as a subcategory within the current "vegetables and legumes/beans" food group.
- Mushrooms support positive health outcomes.

The current subcategories of vegetables

The current "vegetables and legumes/beans" food group is divided into five subcategories: 'dark green or cruciferous/brassica', 'orange vegetables', 'root/tubular/bulb', 'legumes/beans' and 'other vegetables'. This categorisation is based on nutritional composition, with each subcategory a unique source of key or distinguishing nutrients:

- **Dark green or cruciferous/brassica:** folate.
- **Orange vegetables:** vitamin A.
- **Root/tubular/bulb:** carbohydrate.
- **Legumes/beans:** protein and iron.

The potential for mushrooms to increase vitamin D intake

Mushrooms are classified within the "other vegetables" category, alongside many of the salad vegetables, yet vitamin D is a distinguishing nutrient for mushrooms.

Dietary modelling was conducted [30] to quantify the effect of an additional 'mushrooms' subcategory within the "vegetables and legumes/beans" core food group on the nutrition composition of the 2011 *Foundation Diet*, used in the revision of the 2013 Australian Dietary Guidelines (ADG) [12].

The effect of different serve numbers per week, both in substitution for serves of "other vegetables" and in addition to the current recommended number of vegetables serves, was assessed. Two different *Foundation Diets* were modelled, based on the highest degree of difference in nutritional composition:

- Omnivore
- Ovo-lacto vegetarian

Three demographic groups were tested, based on the highest degree of difference in Adequate Intake levels for vitamin D:

- Women 19-30 years (Adequate Intake = 5 µg/day)
- Men 51-70 years (Adequate Intake = 10 µg/day)
- Women 71+ years (Adequate Intake = 15 µg/day)

The results of this dietary modelling [30] showed that the addition of 'mushrooms' as a new subcategory of vegetables improved vitamin D intakes for all demographic groups analysed (**Table A1**).

Omnivore diet:

- Substitution of 7 serves of 'other vegetables' for 7 serves of white button mushrooms per week increased vitamin D intakes for:
    - Women aged 19-30 years: by 55%, to 5.1 µg/day, meeting 101% of the Adequate Intake.
    - Men aged 51-70 years: by 41%, to 6.5 µg day, meeting 65% of the Adequate Intake.
    - Women aged 70+ years: by 41%, to 6.5 µg /day, meeting 43% of the Adequate Intake.
- Substitution of 3 serves per week increased vitamin D intakes by 15-18% across demographic groups. No group was able to meet the Adequate Intake for vitamin D at this level of consumption.
- Almost identical results were obtained when mushrooms were incorporated via addition (serves added on top of current vegetables serves), rather than via substitution (serves added in place of "other vegetables" serves), for all demographic groups.

Ovo-lacto vegetarian diet:

- Substitution or addition of mushrooms for other vegetables at 7 serves per week shows an 86% to 120% increase in vitamin D intakes across the demographic groups, and an approximate doubling in the ability of all groups to meet the Adequate Intake for vitamin D.

Effect on the intake of other nutrients

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Omnivore diet:

In the dietary modelling, when 7 serves of 'other vegetables' per week was substituted with 7 serves of 'mushrooms' per week, there were small decreases in the provision of some nutrients compared to the original *Foundation Diets*, such as riboflavin, folate, vitamin C, and zinc, but diets still met the Nutrient Reference Value for all nutrients and for all demographic groups. There was also a small increase in the provision of iron for women aged 19-30 years and magnesium for men aged 51-70 years.

With the addition of 7 serves of mushrooms per week, on top of the existing 14 serves of 'other vegetables' used within the original *Foundation Diets*, micronutrient intakes only increased, and energy intake was minimally affected (1% increase).

Ovo-lacto vegetarian diet:

The addition of 'mushrooms' as a separate subcategory of vegetables had a notable effect on selenium, which is an at-risk nutrient for some population groups in the *Foundation Diets*. This suggests a role for mushrooms in supporting the intake of selenium within a vegetarian diet:

- **Women 19-30 years:** the addition or substitution of 3 serves/week of mushrooms increased selenium intakes from 97% to 104% Recommended Daily Intake (RDI), and selenium intakes increased to 120% of the RDI when 7 serves/week of mushrooms were modelled.
- **Men aged 51 to 70 years:** the addition of 3 serves of mushrooms/week increased selenium intakes from 93% to 101% RDI, and 7 serves per week took selenium intakes to 114% of the RDI.
- **Women aged 70+ years:** selenium intakes increased from 79.5% to 105% of the RDI when 7 serves/week of mushrooms were modelled, either by addition or substitution.

Results of other dietary modelling studies

Two other dietary modelling papers, published in 2021 [31, 32], estimated the effect on the nutrient intake following the addition of one 84 gram serve of mushrooms in the United States. It was shown in both papers that increasing mushroom consumption can have a beneficial impact on the intake of key nutrients and reduce levels of micronutrient inadequacy, with minimal impacts on energy, carbohydrate, fat, and sodium levels.

When one 84 g serve of *A. bisporus* mushrooms was added to the US diet, there was:

- Increased dietary fibre, copper, potassium, selenium, riboflavin, and niacin in both usual intakes and recommended USDA Food Patterns.
- Increased phosphorus, zinc, and choline in usual intakes for both adolescents and adults.
- Increased iron, thiamine, folate, and vitamin B6 in usual intakes of adults.
- A decrease in the percent of the population with intakes below the Estimated Average Requirement for copper, phosphorus, selenium, zinc, thiamine, riboflavin, niacin, folate, and vitamin B6 for adults over 19 years of age.

- An increase in bioactives, with mushrooms contributing an additional of 2.2 mg ergothioneine and 3.5 mg glutathione to the daily diet.

The bioactive composition of mushrooms

It is a widely recognised that a wide variety of bioactives is important for good health [33]. The characterising bioactives in vegetables are the carotenoids [27], a family of red, orange, and yellow bioactive pigments. The predominant bioactive compounds of mushrooms are largely different to vegetables and include ergothioneine, beta-glucan, chitin, glutathione, and phytosterols (particularly ergosterol):

- **Ergothioneine:** A sulfur-containing amino acid produced only by fungi and some cyanobacteria and mycobacteria [34]. Potent antioxidant activity of importance for human health with a dedicated ergothioneine transporter present in many human tissues [34]. Mushrooms contain the highest ergothioneine levels of any dietary source [34].
- **Beta-glucans:** Polysaccharides, chains of sugar units with a structural role in the fungal cell wall [35]. Identified as having a range of beneficial health effects, including immunomodulatory, anti-inflammatory, anti-viral, and anti-cancer activity, as well as benefits for cardiometabolic (cholesterol-lowering activity) and digestive (prebiotic activity) health [36].
- **Chitin:** A structural carbohydrate present in the mushroom cell wall [37, 38]. Health effects in humans include prebiotic and cholesterol-lowering effects [37]. The only other food sources of chitin (in addition to other fungi) are crustaceans and insects [37].
- **Glutathione:** Peptide of 3 amino acids produced by the human body, known as the body's "master" antioxidant. Low glutathione levels have been associated with increased risks for cancer, cardiovascular diseases, arthritis, and diabetes [34], and dietary intake of glutathione may be important for the maintenance of optimal glutathione levels [34].
- **Phytosterols (including ergosterol):** Cholesterol-like substances found in plants, serving as structural components of biological membranes [39]. Identified health benefits include cholesterol-lowering and potential blood pressure lowering properties, as well as anti-cancer, anti-inflammatory, and anti-oxidation activities [39]. Ergosterol, on exposure to UV light, can be photosynthetically converted to vitamin D_2 [15].
- **Others:** A range of additional bioactives are present in mushrooms, including flavonoids, phenolic acids, bioactive peptides, additional bioactive polysaccharides, and enzymes [40-48].

The health effect of mushrooms

Mushroom consumption has been associated with a range of positive health outcomes in scoping and systematic reviews of observational and clinical studies [49-51], including beneficial effects on:

- Markers of inflammation and immune function,
- Satiety,
- Cancer risk (total, breast, and ovarian),
- Gut microbiota,
- Markers of cardiovascular health,

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- Cognitive function, and
- All-cause mortality risk.

Recommendation 3: Provide specific practical recommendations for enhancing the vitamin D content of mushrooms: buying vitamin D enriched mushrooms and/or putting mushrooms in sunlight (for 15 to 60 minutes).

Scientific rationale:

Will help to address low vitamin D intakes:

- The vitamin D content of mushrooms can increase 10-fold when exposed to UV-light.
- The vitamin D content of mushrooms exposed to UV-light (18 µg/75 grams) dwarfs that of other foods, including eggs (7.1 µg/120 grams) and salmon (4.9 µg/100 grams).
- Dietary modelling has shown that the addition of as little as 1 serve of UV-exposed mushrooms per week can meet the Adequate Intake of vitamin D.
- High-level evidence supports that UV-mushrooms increase vitamin D status. The efficacy of UV-mushrooms for increasing vitamin D status can be equivalent to vitamin D supplements.

In addition:

- There is high retention of vitamin D in mushrooms during both storage and cooking.

The vitamin D content of UV-mushrooms

Mushrooms produce their own vitamin D_2 on exposure to UV-light, such as from sunlight or UV lamps [15]. This increase is large: the vitamin D content of a 75 gram serve of mushrooms exposed to UV light can provide greater than 100% of vitamin D needs [15]. This large increase in vitamin D upon UV-light exposure is a result of their ergosterol content (a vitamin D precursor) which is unique to fungi.

The vitamin D content of mushrooms exposed to UV light dwarfs the vitamin D content of other vitamin D-rich foods, including eggs and salmon [26]:

- **Mushrooms, common, exposed to UV-light:** 18 µg/75 grams
- Eggs, hard-boiled: 7.1 µg/120 grams
- Salmon, grilled: 4.9 µg/100 grams
- Breakfast cereal, fortified with vitamin D: 2.5 µg/40 grams
- **Mushrooms, common:** 1.6 µg/75 grams

- Margarine: 0.7 µg/10 grams
- Cow's milk, fortified with vitamin D: 1.25 µg/250 mL
- Cow's milk, unfortified: 0.25 µg/250 mL
- Vegetables, all: 0 µg / 75 grams

The specific content of vitamin D in mushrooms exposed to UV-light depends on the amount of UV-exposure, as well as surface area, mushroom type, light intensity, and length of exposure:

- The Australian Food Composition Database (AFCD) value for UV-exposed white button mushrooms is 18 µg/75 g fresh mushrooms (180% RDI), an increase of over 10-fold compared to non-UV exposed white button mushrooms [26]. These mushrooms were exposed to 1-2 seconds of UV light after harvesting.
- UVB radiation with a UV lamp has produced vitamin D_2 concentrations up to 240 µg/75 g fresh weight (240% RDI) [15].
- The vitamin D content of sliced mushrooms was 13.1 µg/75 g fresh weight (131% RDI) after 15 minutes of midday and mid-summer sun exposure in Germany, and reached 24.4 µg/75 g fresh weight (244% RDI) after 60 minutes of sun exposure [52]. Sliced mushrooms produce higher levels of vitamin D compared to whole mushrooms due to the increased surface area [15].

The potential for mushrooms to improve vitamin D status

Mushrooms exposed to UV-light consistently increase blood levels of vitamin D2 (25-hydroxy D2, or 25(OH)D2), including in randomised controlled trials [49] [53] [54, 55]:

- A 2023 systematic literature review identified that vitamin D dosages of 15 to 95 µg/day from UV-exposed mushrooms directly increased serum levels of vitamin D2 [53].
- UV-exposed mushrooms providing 50 µg vitamin D/day have been shown to be equivalent to a vitamin D supplement for increasing serum vitamin D levels [49].

The potential for UV-mushrooms to increase vitamin D intake

In recent dietary modelling [30], the addition of 'UV-mushrooms' as a new subcategory of vegetables within the 'vegetables and legumes/beans' food group enabled vitamin D Adequate intake levels to be met with between just 1 to 4 serves per week (1 serve = 75 grams) of UV-exposed mushrooms, for all demographic groups analysed (**Table A2**), and for both the omnivore and ovo-lacto vegetarian diets:

- **Women aged 19-30 years:** one serve per week was sufficient to meet the Adequate Intake value for the Omnivore dietary pattern, with 2 serves per week required for the Ovo-Lacto Vegetarian dietary pattern.
- **Men aged 51-70 years:** 2 serves of UV-exposed mushrooms per week were required to meet the Adequate Intake, regardless of diet (omnivore or vegetarian).
- **Women aged 70 plus years:** 4 serves of UV-exposed mushrooms per week were required to meet the Adequate Intake, regardless of diet (omnivore or vegetarian).

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Retention of vitamin D content

There is high retention of the vitamin D content of mushrooms after both cooking and storage:

- **Storage:** There is little to no impact on the vitamin D levels of mushrooms after refrigeration for 8 days [15].
- **Cooking:** Vitamin D is generally well retained in cooking [15, 48, 56]. For example, frying had only a 12% reduction in vitamin D after both low and high heat for 20 minutes [15, 48].

Summary of recommendations to adequately address low vitamin D intakes.

1. Change the wording of the current "Vegetable and legumes/beans" food group to, "Vegetables, mushrooms, and legumes/beans".

2. "Mushrooms" to be an additional subcategory within the "Vegetables, mushrooms, and legumes/beans" food group.

3. Provide specific practical recommendations for enhancing the vitamin D content of mushrooms: buying vitamin D enriched mushrooms and/or putting mushrooms in sunlight (15 to 60 minutes).

B. Provide greater practical advice to lower sodium intake.

Recommendation 4: Provide specific practical recommendations for using foods high in umami and low in sodium, such as mushrooms, as a strategy for reducing sodium intake.

Scientific rationale:

Will help to lower sodium intakes:

- Umami flavour is well established to reduce salt intake while maintaining flavour.
- Mushrooms are a rich source of umami.
- There is direct evidence that substituting foods with added salt for mushrooms within a meal reduces sodium intake and can maintain sensory attributes.

The role of umami in reducing intake of added salt

The Australian Dietary Guidelines recommend limiting the intake of foods and drinks high in added salt, yet sodium intake exceeds recommended levels [57].

The replacement of sodium with umami flavour in foods has been suggested as one method to reduce sodium intake while maintaining flavour and acceptance. A 2022 scoping review, including 52 studies (interventional and observational research), identified a beneficial effect of the addition of umami flavour for sodium reduction in foods whilst maintaining acceptance [57]. Umami flavour was predominantly added via monosodium glutamate, but also included foods such as tomato, mushrooms, and yeast. Dietary modelling conducted in 2023 [58] estimated that the universal (100%) incorporation of umami substances into food items would reduce the salt intake of Japanese adults by 12.8 to 22.3% at the population level (equivalent to 1.27 to 2.22 g of salt reduction per day).

While umami flavour is present in a range of different foods, the sodium content of these foods differs (**Table A3**). To reduce sodium intake with the use of umami, recommendations should be incorporate foods with umami flavour that are also low in sodium.

Mushrooms as a source of umami

Mushrooms are low in sodium (9 mg / 100 grams) [26] and have a rich umami taste and aroma. Their savoury umami flavour is produced by a combination of the amino acids' glutamate and aspartate and 5'-nucleotides (such as 5'-inosinemonophosphate), as well as volatile compounds and other components [1, 59].

Their umami flavour is enhanced via high heat (such as in oven roasting) due to the Maillard reaction; this chemical reaction between amino acids and sugars with heat leads to caramelisation and its accompanying flavour [59]. Umami compounds in mushrooms also interact with those in other umami-rich ingredients (such as tomatoes) to have a synergistic effect on flavour, increasing both depth and length of taste [1].

Direct evidence for mushrooms reducing salt intake

In experimental studies, it has been shown that mushrooms can be used in meals as a substitute for foods high in added salt, including beef patties, taco fillings, chicken patties, and sausages, to reduce salt intake in the diet, with comparable sensory profiles and liking scores (**Table A4**).

Summary of recommendations to lower sodium intake.

1. Provide specific practical recommendations for using foods high in umami and low in sodium, such as mushrooms, as a strategy for reducing sodium intake.

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C. Provide greater practical advice to help relevant population groups to lower red meat intake without increasing ultra-processed or discretionary food consumption.

Recommendation 5: Provide specific practical recommendations to reduce red meat intake using mushrooms as a substitute, for relevant demographic groups.

Scientific rationale:

Will help to reduce red meat intakes for relevant demographic groups, without increasing the intake of ultra-processed or discretionary foods:

- Mushrooms have a meaty texture and mouth-feel.
- There is direct evidence that substituting red meat for mushrooms can enhance or maintain sensory attributes and liking scores.
- Many other meat-alternatives are ultra-processed with unfavourable nutritional profiles.
- Mushrooms are a minimally processed, core food.

In addition:

- The substitution of red meat for mushrooms may reduce cost and have beneficial environmental impacts.

The sensory profile of meat and mushrooms

A reduction in red meat is an increasing focus of dietary guidelines globally, to reduce chronic disease risk and improve environmental sustainability [60]. In the current ADG, red meat is a core food, but the weekly consumption of red meat is recommended to be limited to no more than 455 grams due to the association of red meat to certain cancers. Australian men, on average, consume red meat in greater quantities than recommended levels [61]. Red meat however has unique sensory properties, such as texture and flavour, which have been identified as key barriers to reducing meat intake [62].

Mushrooms have a high moisture content that contributes to a meaty texture and mouth-feel [1]. This enables mushrooms to be substituted for meat in vegetarian dishes or meals while maintaining a similar mouthfeel [1].

Evidence for the substitution of red meat with mushrooms

There is consistent evidence from experimental studies that the substitution of up to 80% meat with mushrooms results in equal or superior sensory appeal and flavour (**Table A4**). In these studies, the replacement of meat for mushrooms was accompanied by lower energy, sodium and saturated fat, and higher fibre and potassium intakes.

Comparison of mushrooms to other meat substitutes

While consumer demand for plant-based meat alternatives has increased [63], many meat-alternative products can be high in saturated fat and may not provide the nutritional benefits as the whole food from which they were derived [62, 63]. A recent cross-sectional study identified that 84% of meat alternatives were ultra-processed when classified according to the NOVA system [63].

Mushrooms, on the other hand, are a whole, unprocessed food that can assist in overcoming the barriers to decreasing meat consumption.

Other impacts

Cost

The replacement of meat for mushrooms can result in cost savings. Based on the lowest costs identified for trimmed red meat ($1.60 per 100 g) and white button mushrooms ($1.27 per 100 g) at the major Australian supermarkets of Coles and Woolworths in April 2023:

- Substitution of 50% red meat for mushrooms (weight for weight) produced a savings of 11%.
- Substitution of 75% red meat for mushrooms (weight for weight) produced a savings of 28%.

Environment

Mushrooms also have a significantly lower environmental impact (0.5 kg CO2 per pound consumed), (measured by carbon footprint) in comparison to red meat (5.5 kg CO2 per pound consumed) [64], indicating that the substitution of red meat for mushrooms has additional environmental benefits.

Summary of recommendations to lower red meat intake in relevant demographic groups without increasing ultra-processed or discretionary food consumption.

1. Provide specific practical recommendations to reduce red meat intake using mushrooms as a substitute, for relevant demographic groups.

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Appendices

Table A1. Effect of the addition of *A. bisporus* (white button) mushrooms as a subcategory of vegetables on daily vitamin D[1] intake within Foundation Omnivore and Ovo-Lacto Vegetarian diets.

DEMOGRAPHIC GROUP	NRV (AI) FOR VITAMIN D (µg/day)	FOUNDATION DIET		+ 3 SERVES MUSHROOMS/WEEK		+ 7 SERVES MUSHROOMS/WEEK		NUMBER OF MUSHROOM SERVES/WEEK TO MEET AI
		VITAMIN D (µg/day)	%NRV	VITAMIN D (µg/day)	%NRV	VITAMIN D (µg/day)	%NRV	
Omnivore diet								
Women 19-30 years	5	3.3	65	3.9	78	5.1	**101**	7
Men 51-70 years	10	4.6	46	5.3	53	6.5	65	19
Women 70+ years	15	4.5	30	5.3	35	6.5	43	36
Ovo-lacto vegetarian diet								
Women 19-30 years	5	1.5	30	2.1	42	3.3	66	13
Men 51-70 years	10	2.2	22	2.9	29	4.1	41	27
Women 70+ years	15	2.1	14	2.9	19	4.1	27	44

[1] Vitamin D_2 and D_3

AI, adequate intake; µg, micrograms; NRV, nutrient reference value.

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Table A2. Effect of the addition of UV-exposed (vitamin D-enhanced) *A. bisporus* (white button) mushrooms as a subcategory of vegetables on daily vitamin D intake[1] within Foundation Omnivore and Ovo-Lacto Vegetarian diets.

DEMOGRAPHIC GROUP	NRV (AI) FOR VITAMIN D (μg/day)	FOUNDATION DIET		+ 1 SERVE UV-MUSHROOMS/WEEK		+ 3 SERVES UV-MUSHROOMS/WEEK		NUMBER OF UV-MUSHROOM SERVES/WEEK TO MEET AI
		VITAMIN D (μg/day)	%NRV	VITAMIN D (μg/day)	%NRV	VITAMIN D (μg/day)	%NRV	
Omnivore diet								
Women 19-30 years	5	3.3	65	6.4	127	13.1	262	1
Men 51-70 years	10	4.6	46	7.8	78	14.5	145	2
Women 70+ years	15	4.5	30	7.7	52	14.5	97	4
Ovo-lacto vegetarian diet								
Women 19-30 years	5	1.5	30	4.6	92	11.3	227	2
Men 51-70 years	10	2.2	22	5.4	54	12.1	121	2
Women 70+ years	15	2.1	14	5.4	36	12.1	81	4

[1] Vitamin D_2 and D_3

AI, adequate intake; μg, micrograms; NRV, nutrient reference value.

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Table A3. Umami and sodium content of umami-rich foods [1, 65]

FOOD	GLUTAMATE (mg/100g)	SODIUM (mg/100g)
Common mushrooms	40 – 100	9
Fresh shiitake mushrooms	70	9
Potatoes, raw	30 – 100	6
Sweet potatoes, raw	60	55
Tomatoes, red/ripe	150 – 250	5
Carrots, raw	40 – 80	69
Parmesan cheese, dry grated	180	1529
Soy sauce	400 – 1700	5493
Beef ground, 80% lean	10	66
Pork tenderloin, raw	10	53
Chicken ground, raw	20 – 50	60

mg, milligrams

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Table A4. The effect of inclusion of fresh mushrooms as a meat substitute on nutritional profile and sensory scores.

FOOD	NUTRITION	SENSORY ANALYSIS
Taco filling [66, 67]	↓ sodium, saturated fat	Equivalent to all-meat control, even with reduced salt.
Beef patties [68]	↓ sodium, fat	Equivalent to all-meat control and better liked than substitution using TSP.
Chicken nuggets [69]	↓ sodium, fat, protein; ↑ carbohydrate, fibre	Comparable to all-meat control but decreased flavour with sodium reduction.
Frankfurters [70]	↓ sodium, fat; ↑ dietary fibre;	Acceptable, though lower colour, flavour, and taste vs control.

↑, increase; ↓, decrease; ↔, no change

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Bringing mushrooms from the shadows to centre stage in the Australian Dietary Guidelines

In the world of nutrition, even the most mundane details can have a profound impact on our health and wellbeing. Enter the Australian Dietary Guidelines (ADG) - a comprehensive blueprint designed by the Australian Government to steer us towards better dietary choices.

By Leah Bramich, AMGA

The Australian Dietary Guidelines (ADG) are used by consumers, health care professionals and schools, as the benchmark for dietary advice for all Australians. Nestled within these guidelines, mushrooms are classed as a vegetable.

However, the current (2013) guidelines are under review and due for update in 2025. This provides an opportunity to advocate for a more prominent position for mushrooms, which will help to highlight their unique nutritional composition.

In the current iteration of the ADG, mushrooms find themselves tucked away in the 'other vegetables' subcategory of the 'vegetables and legumes/beans' group. However, mushrooms belong to the Fungi Kingdom, which sets them apart with their distinct nutritional profile and health benefits. This is not recognised in the current ADG, which may be a missed opportunity to improve nutrient intake and generally improve the Australian diet.

The Australian Mushroom Growers Association (AMGA) is advocating for the repositioning of mushrooms in the ADG, using scientific evidence provided by Nutrition Research Australia (NRAUS), via the levy-funded project MU22001 – *Scientific basis for a mushroom food group in the Australian Dietary Guidelines.*

The project consists of four phases, with AMGA talking the lead in Phase 4.

Phase 1: Determine the best strategic pathways to help achieve repositioning in the updated 2025 ADG. This has been completed and a decision was made to advocate for mushrooms to be its own subcategory within a revamped 'vegetable, legumes/beans, and mushrooms' food group.

Phase 2: Collate the relevant evidence to support repositioning in the form of a scientific summary report. This is to include dietary modelling to capture the nutritional impact that such a change would have on key population groups in Australia.

Phase 3: Translation of this science into key messages that will support the mushroom industry with making a submission to the ADG.

Phase 4: The AMGA will independently advocate for a change to the ADG, by using the scientific evidence to initiate a PR campaign.

With Phase 2 of the project (the scientific summary report) now complete, NRAUS have collated some exciting scientific data to help justify why mushrooms are worthy of being highlighted in the ADG.

The report addresses six research questions:

1. What is the biological classification of mushrooms and how does this differ to vegetables?
2. What is the nutritional composition and contribution of mushrooms to the diet and how does this differ to vegetables?
3. What is the significance of mushrooms being a source of vitamin D?
4. What are the key culinary properties of mushrooms and how does these differ from vegetables?
5. What are the unique health effects associated with mushroom consumption and how do these differ from vegetables?
6. What is the effect on nutritional intake if mushrooms were to become their own subcategory within the vegetable food group?

The key findings are summarised in the table below.

Table 1. Key findings of the scientific report relating to a mushrooms sub- category within the vegetables core food group of the Australian Dietary Guidelines.

Biologically distinct	• Mushrooms are not vegetables and belong to a distinct biological kingdom, fungi.
Nutritionally distinct	• Mushrooms provide a unique set of nutrients to the diet that is different to vegetables. • Mushrooms also contain a different complement of bioactives to vegetables. • Dietary modelling has shown that increasing mushroom intake can make a significant contribution to the intake of key dietary nutrients that vegetables do not provide.
Vitamin D is a key distinguishing ingredient	• Mushrooms are a source of vitamin D and, when exposed to UV light, provide 100-300% of dietary needs. • Vitamin D deficiency is a global problem with no clear solution. • Vitamin D intakes in Australia are low and it is difficult to meet vitamin D needs. • There is precedent in dietary guidelines to recognise foods with unique nutrient compositions or different 'distinguishing' nutrients, yet the current ADG do not recognise the unique nutritional composition of mushrooms.
Culinary distinct	• Mushrooms have unique culinary properties from vegetables including an umami flavour and meat-like texture. • Mushrooms can be used as meat substitutes with comparable or increased liking scores and improved nutrient intakes. • The substitution of meat with mushrooms can provide cost savings and environmental benefits.
Unique health benefits	• Unlike vegetables, UV-exposed mushrooms improve vitamin D status and may reduce ovarian cancer risk. • This is due to their bioactive profile, which is distinct from vegetables.
Validated by dietary modelling	• Current recommended diets in the ADG are deficient in vitamin D and vegetarian diets are deficient in vitamin D and selenium. • The adoption of a new 'mushrooms' subcategory of vegetables will produce notable increases in vitamin D intakes for adult males and females. • This effect is amplified with UV-exposed mushrooms, where vitamin D needs were met with as little as 1 x 75 gram serve per week for women aged 19-30 years. • One 75 g serve of mushrooms per day also enabled ovo-lacto vegetarian adults to meet their selenium requirements.

The Australian Dietary Guidelines (ADG) aim to support health and provide Australians with a sufficient intake of all nutrients within a diet. This is achieved by grouping foods based on similar nutritional compositions. However, the current ADG do not meet vitamin D needs or acknowledge the distinct nutritional composition of mushrooms.

Scientific evidence supports the claim that mushrooms have a unique nutritional composition, including being a source of vitamin D, which is explained by their unique biology.

Dietary modelling confirmed that categorising mushrooms as its own subcategory of foods within the 'Vegetables and legumes/beans' food group would have a notable impact on vitamin D intake. Their culinary properties are also diverse to vegetables, and they can help to reduce sodium and saturated fat intake, and increase fibre and potassium intake, via meat replacement in meals.

Together, the evidence shows that revamping the position of mushrooms within the ADG has a beneficial effect on modelled micronutrient intakes in the Australian population and the potential to make a significant contribution to solving current public health challenges.

Hort Innovation MUSHROOM FUND

This project has been funded by Hort Innovation using the mushroom research and development levy and funds from the Australian Government. For more information on the fund and strategic levy investment visit horticulture.com.au

Mushrooms in the Australian Dietary Guidelines: Opinion Piece Manuscript

Prepared for:

Australian Mushroom Growers Association
August 2023

Prepared by:

Nutrition Research Australia Pty Ltd

Background

Mushrooms as Part of the Solution to Vitamin D Deficiency

Vitamin D deficiency is a public health issue worldwide, with low vitamin D intakes a contributing factor (1). While recent literature has suggested that policy-driven leadership is needed to address low vitamin D status (1), current dietary recommendations and guidelines both in Australia (2) and worldwide (3) have not been able to provide dietary patterns that allow for adequate vitamin D intake. However, these guidelines did not consider mushrooms as a source of vitamin D.

White button mushrooms (*Agaricus bisporus*) are both the most commonly-consumed mushrooms as well as a source of vitamin D in Australia, and have the ability to both produce over 100% of vitamin D needs per serve (75 g) on exposure to UV-light (4) and meaningfully increase vitamin D status (5) indicating that mushrooms can play a role in addressing low vitamin D intakes and vitamin D deficiency. Mushrooms also provide additional nutrients and bioactives (4, 6), possess unique culinary properties (7, 8), have been associated with a range of beneficial health outcomes (5), and have a low carbon footprint (9). Together, these features place mushrooms as an important dietary vitamin D source that align with global sustainability and animal-reducing/plant-forward movements. However, the role of mushrooms in helping to address vitamin D deficiency in a healthy, non-animal, and sustainable fashion is not widely recognised. There is a need for the role of mushrooms in human health to be communicated and promoted within the academic community.

The Brief

The Australian Mushroom Growers Association, on behalf of Hort Innovation, is advocating for the repositioning of mushrooms in the Australian Dietary Guidelines (ADG) and commissioned Nutrition Research Australia (NRAUS) to support with the strategic direction and collation of the scientific evidence. The project has four deliverables, the first three of which have been completed:

- **Deliverable 1:** Strategic plan that identifies the optimal strategic pathway for the positioning of mushrooms in the updated 2025 ADG.
- **Deliverable 2:** Scientific report that collates the scientific evidence to support this repositioning via scientific literature review and dietary modelling.
- **Deliverable 3:** Key messages report that translates the scientific evidence to support the mushroom industry in undertaking a submission to the ADG.
- **Deliverable 4:** Published opinion piece that utilises the scientific evidence and key messages collected to date for the purpose of creating impact and awareness in the academic community, on the role of mushrooms in addressing vitamin D deficiency.

This report presents the draft opinion piece manuscript, to be submitted for publication to the journal “Advances in Nutrition”. Journal-specific formatting will take place during the submission process.

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Manuscript

Title:

A food-based solution to vitamin D deficiency? Perspective on the untapped role of mushrooms.

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Abstract

Recent literature has highlighted that vitamin D deficiency and insufficiency is a public health issue in Australia and globally, with low dietary vitamin D intake a contributing factor. Nutrition policies should help address vitamin D deficiency, yet most dietary guidelines do not meet proposed vitamin D requirements and supplementation is recommended to increasing vitamin D intakes. Rates of vitamin D deficiency are 31% in Australia, and as high as 72% in some regions (Eastern Mediterranean) globally, indicating that complementary approaches to supplementation are needed. Edible mushrooms such as *Agaricus bisporus* are a source of vitamin D in Australia and can produce over 100% of recommended vitamin D needs (5 to 15 µg/day, depending on demographic group and recommending body) per 75 g serve (18 µg; 24.2 µg/100 g) on exposure to UV-light. They also provide additional nutrients and unique bioactives, have distinct culinary properties allowing for the partial substitution of meat and sodium in the diet, and their consumption has been associated with a wide range of beneficial health outcomes. This includes the ability of UV-exposed mushrooms to increase vitamin D status with equivalent efficacy to vitamin D supplements (25 µg). Mushrooms are a sustainable food choice and align with global trends towards diets reduced in animal foods. We propose and showcase evidence that mushrooms represent a key tool in the strategy to addressing vitamin D deficiency both in Australia and globally and call on health authorities to take a lead in the recognition and promotion of mushrooms as a natural, vegan, and sustainable vitamin D food source.

Keywords: Vitamin D deficiency, vitamin D intakes, mushrooms, dietary guidelines, recommended

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Vitamin D deficiency and inadequate intake is a global problem.

Vitamin D deficiency is a global health concern with significant implications for population health. High-level reviews (10-15), indicate that rates of vitamin D deficiency, when defined as blood level <50 mmol/L (1, 16), are as high as 47.9% on average globally, with a range from 19% (Africas) to 72% (Eastern Mediterranean), depending on the region (10) (**Table 1**). In Australia, almost three quarters of the population have suboptimal vitamin D status. Vitamin D deficiency is 31% (10), and insufficiency (50 to 75 mmol/L) occurs in a further 43% of adults (17) and 16% of pre-school children (18). While age is a key predictor of vitamin D deficiency in Australia, with children and adults having the lowest and highest levels, respectively (19), some population groups are more vulnerable, with deficiency rates of up to 94% in residential care-elderly (20, 21) and 27% in pregnant women (11). Along with its well-established role in bone health (22), studies have linked vitamin D deficiency or insufficiency to increased susceptibility to infectious diseases (including COVID-19 and upper respiratory tract infection), muscle weakness, multiple sclerosis, diabetes, hypertension, metabolic syndrome, cancers, autoimmune diseases, cardiovascular disease, and hip or vertebrae fracture in later life (10). In addition, vitamin D deficiency during pregnancy has been linked to an increased risk for gestational diabetes (23). Together, the evidence is clear: the “sunshine” vitamin requires a metaphorical light to be shined upon it, and on a global scale.

Table 1. Rates of vitamin D deficiency[1] and mean vitamin D intakes in Australia and World Health Organisation global regions.

COUNTRY/REGION[2]	RATE OF VITAMIN D DEFICIENCY[1]	MEAN VITAMIN D INTAKE (µg/day)	REFERENCES
Australia	31%	1.84 to 3.25	(1)
Africas	19%	1 to 9.6	(24)
Eastern Mediterranean	72%	1 to 4	(25)
Europe	53%	2 to 4	(25-28)
Americas	30%	3.5 to 6	(29, 30)
South-East Asia	57%	1.5–5.5	(26)
Western Pacific	44%	1.84 to 7.6	(1, 26)

[1] Defined as <50 mmol/L (1, 16). Rates of deficiency sourced from Cui 2023 meta-analysis (10).

[2] World Health Organisation (WHO) regions (10), with Australia considered separately.

Current vitamin D guidelines in Australia suggest that sunlight is the best source of vitamin D, with supplements as the recommended alternative, and diet considered a poor source (1, 2, 21, 31, 32), yet increased vitamin D intake has been consistently shown to improve vitamin D status (33). Global vitamin D intakes are lower than the estimated average requirement (EAR) for vitamin D of 10 µg/day set by the Institute of Medicine (34) (**Table 1;** a description of the different globally recommended intakes referred to in this perspective is provided in **Box 1**). The recommended dietary patterns provided by dietary guidelines are also insufficient for vitamin D (2, 3) and mean intakes in Australia are among the lowest in the world at 1.84 to 3.25 µg/day (1). Deficiency data also show that sunlight exposure is insufficient to maintain vitamin D adequacy, including in

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countries such as Australia, where the potential for daily sunlight exposure is high. Many factors are suggested to play a role including indoor lifestyles, skin colour, and skin cancer risk (35). In addition, vitamin D from sunlight exposure varies according to season, with a 1.7 fold higher global vitamin D deficiency rate between winter/spring compared to summer/autumn, and higher rates in people living in areas of high latitude (10). An increased focus on addressing and improving vitamin D intake is needed, and the development of strategies and policy for this purpose has been suggested (1).

Box 1: Recommended vitamin D intakes used in this perspective.

- **USA:**
  - Institute of Medicine Estimated Average Requirement (EAR): 10 µg/day

- **Australia:**
  - Adequate Intake (AI) for infants, children, and adults 19-50 years: 5 µg/day
  - AI for adults 51-70 years: 10 µg/day
  - AI for adults >70 years: 15 µg/day

There are four avenues for vitamin D intake to be increased globally: increase in intake of foods naturally high in vitamin D, food fortification with vitamin D, biofortification, or vitamin D supplementation.

The highest food source of vitamin D are predominantly animal-based, such as salmon (5.4 µg/100 g) and eggs (5.9 µg /100 g) (4). Animal-based solutions do not align with plant-based movements, nor do they meet the needs of all population groups (such as those consuming a vegan diet). A recent simulation study suggested that the achievement of adequate vitamin D intake based primarily on animal food sources is not possible within carbon emission limits (36). In contrast, mushrooms are the only natural, non-fortified, and vegan source of vitamin D. Yet, mushrooms as a solution to low vitamin D intakes has been largely overlooked by health authorities, dietary guidelines, and policy makers. This begs the question: have we, as nutrition experts, authorities, and policy-influencers, overlooked a key option for addressing vitamin D deficiency?

Food fortification with vitamin D has been proposed as a key strategy to avoid severe vitamin D deficiency (37) and has been shown to be both efficacious and cost-effective (33). In Finland for example, voluntary vitamin D fortification of fluid milks and margarines/fat spreads was associated with an increase in mean vitamin D status from 47.6 mmol/L in the year 2000 to 65.4 mmol/L in 2011 (33). In the US, fortified milk and milk products provide the greatest contribution (43·7 %) to the dietary vitamin D intake (38). Dietary modelling in Australia has shown that fortification of milk with vitamin D at the maximum permitted level (0.8 µg/100 mL milk) can increase vitamin D intake to 4.9 µg/day but remains below dietary targets (5 µg to 15 µg/day, depending on age group) (39). Further, if all milk and breakfast cereals were to be fortified with vitamin D (1 µg/100 mL and 3.5 µg/100 g, respectively), the average intake of vitamin D from foods would increase to 6.3 µg/day (40), and remain below dietary targets for some population groups. This theoretical level of fortification for milk exceeds the amount permitted in Australia (39, 41) and not all breakfast cereals are permitted to be fortified with vitamin D (42).

While fortification is effective for increasing vitamin D intake, vitamin D deficiency remains prevalent globally, and there is a growing interest in plant-based and animal-reduced dietary patterns, as well as the desire for minimally processed whole foods over fortified foods (43). Thus, a multi-faceted approach that includes natural vitamin D sources could help to support most population groups in achieving vitamin D adequacy.

Biofortification is a recently proposed solution that describes the natural vitamin D enrichment of whole foods including meats, eggs, and fish (via increased vitamin D provision to livestock), as well as mushrooms and yeast (via UV-exposure) (37, 44). For example, the vitamin D_3 content of eggs can be increased by the addition of vitamin D_3 to the feed of hens (44), and the consumption of vitamin D-enhanced eggs was found to be protective of winter time loss in vitamin D status in a randomised controlled trial of Irish adults (45).

Vitamin D supplementation may be an important strategy for increasing vitamin D intakes, particularly for vulnerable groups such as the elderly, and those following a diet that restricts animal foods (10, 11, 20, 46). In Australia, vitamin D supplement use ranges from 0.6% to 17% depending on demographic group, with the highest rates among elderly women (47). Low adherence within the general population, potential for overdosing, and reduced accessibility by those of low socioeconomic status are significant limitations for widespread application to address vitamin D deficiency (10, 11, 20, 33). Supplemental vitamin D is predominantly vitamin D_3, sourced from sheep wool, which is incompatible with a vegan diet (43), although vitamin D2 from fungi is also available .

Mushrooms: a natural and vegan source of substantial vitamin D

Although classified as a "vegetable" within the Australian Dietary Guidelines (ADG), mushrooms are neither vegetables nor plants, but fungi, the third eukaryotic biological kingdom (48). Fungi are more closely related to animals and therefore humans than plants (48, 49), and have the ability to convert ergosterol, a vitamin D precursor, to vitamin D_2 on exposure to UV light (50). In animals, 7-dehydrocholesterol is converted to vitamin D_3 (**Figure 1**) and 7-dehydrocholesterol has also been identified in *Lentinula edodes* (shiitake mushroom), with conversion to vitamin D_3 after UV light and heat (50). Ergosterol (pro-vitamin D_2) is converted to pre-vitamin D_2 under UV-light, with heat required for full conversion to ergocalciferol, vitamin D_2. A novel vitamin D precursor, pro-vitamin D_4, has also been identified in some mushroom species, including *Agaricus bisporus* and *Lentinula edodes*, which is converted to vitamin D_4 in the same manner (50).

Mushrooms can provide over 100% of vitamin D requirements in a single 75 g serve (ADG vegetable serving size) when UV-exposed (4, 46) and between 100% and up to 3000% of vitamin D requirements per 100 g, with the specific content dependent on the amount of UV-exposure, as well as surface area exposed (whole or sliced), mushroom type, light intensity, and length of exposure. These are similar parameters to those determining vitamin D production in human skin (46).

Even non-UV exposed mushrooms can be a source of vitamin D in Australia, with *Agaricus bisporus* (which includes white button, Swiss brown, and portobello varieties) mushrooms providing 16% of the Institute of Medicine EAR per 75 g serve (4, 34). The amount of vitamin D_2 measured and stated in the Australian Food Composition Database (AFCD) for raw white button mushrooms (at point of sale) is 2 µg/100 g (2.14 µg/100 g as vitamin D_3 equivalents). This is in contrast to databases worldwide including the US (51) and New Zealand (52), where the content of white button mushrooms is 0.02 µg/100 g and 0 µg/100 g, respectively. Mushrooms do not naturally contain vitamin D, unless exposed to UV light, meaning that it is likely that those mushrooms analysed at point of sale in Australia would have incidental UV exposure since harvest.

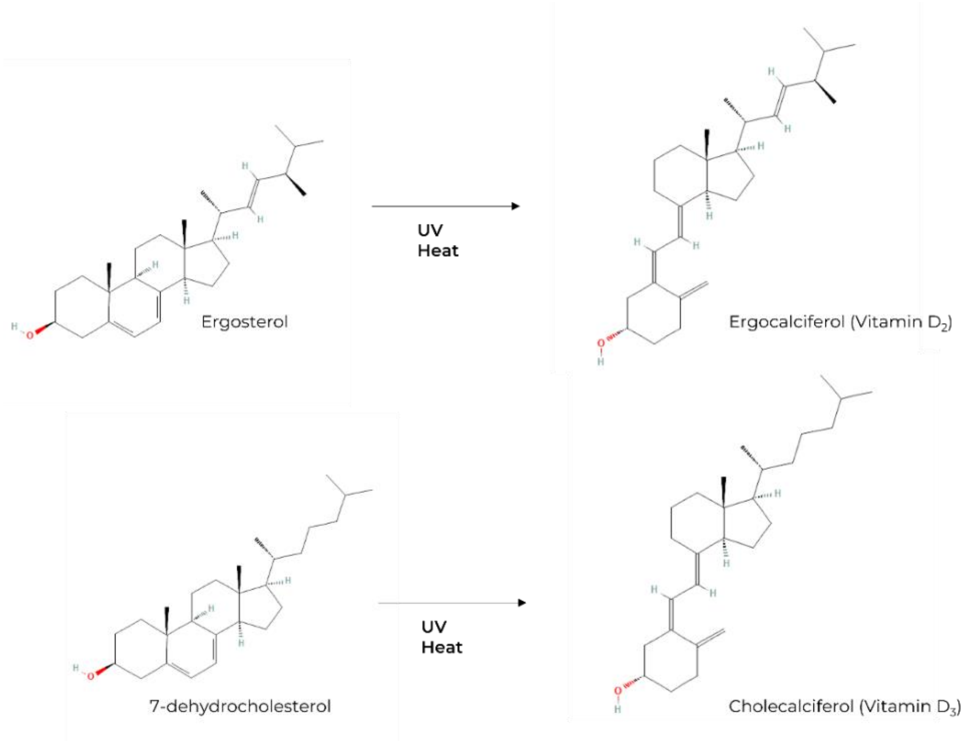

Figure 1. Conversion of pro-vitamin D to vitamin D in mushrooms (ergosterol to vitamin D_2) and animals (7-dehydrocholesterol to vitamin D_3).
Structures sourced from PubChem (53).

In Germany, 100 g of fresh and sliced *A. bisporus* mushrooms exposed to midday, mid-summer sunlight produced 17.5 µg vitamin D_2 after for 15 minutes and 32.5 µg after 60 minutes of sun exposure (54), or to 175% and 325%, respectively, of the National Institute of Medicine EAR (34). Similarly, UVB-lamp pulses (1-2 seconds) of mushrooms after harvest produced 24 µg/100 g (240% EAR) (4), with some studies reporting vitamin D_2 concentrations of up to 320 µg/100 g (3200% EAR) (46). Once produced, vitamin D_2 content remains largely stable for around one week to 10 days when refrigerated (46), corresponding to its shelf life.

Vitamin D production across edible mushrooms varies across species due to ergosterol content. For example, *Pleurotus ostreatus* (oyster) mushrooms were found to generate over double the amount of vitamin D_2 compared to *A. bisporus*, *L. edodes*, and *Pleurotus cystidus* (abalone) mushrooms at the same degree of UV exposure (55). Yet, the vitamin D content of UV-exposed *A. bisporus* mushrooms is notably higher than other dietary vitamin D sources including both oily fish and eggs (**Figure 2**) when expressed per serve size (56).

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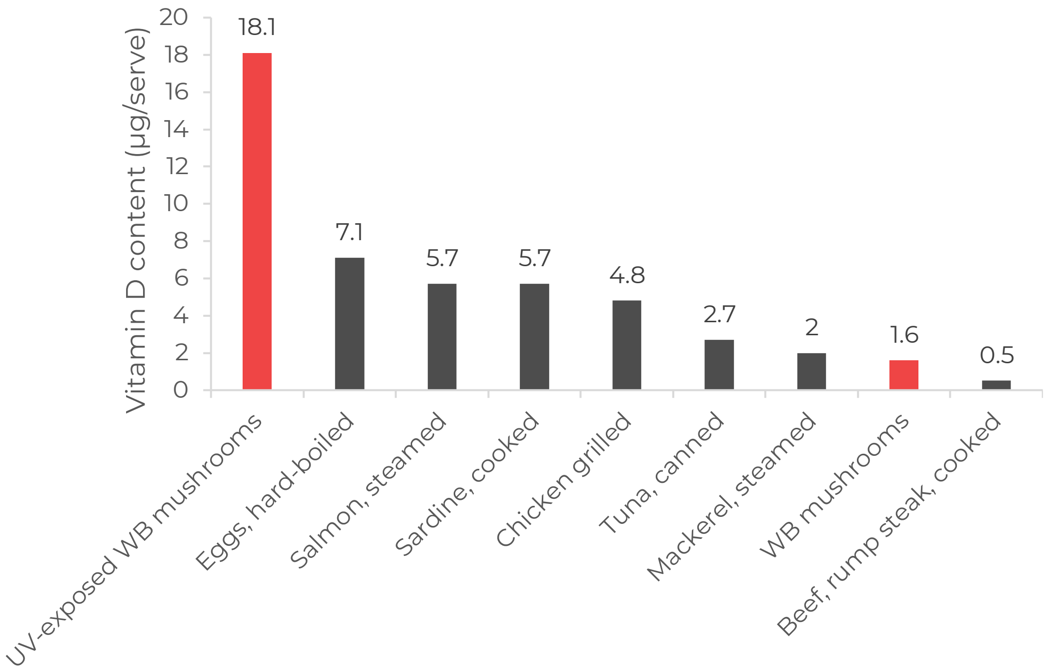

Figure 2. Vitamin D content (µg/serve) of mushrooms and other foods.
Serve sizes as specified in the Australian Dietary Guidelines, with one serve of mushrooms being 75 g (56). WB, white button (raw).

As the only natural and vegan dietary source of vitamin D, mushrooms have a critical role in helping all population groups increase vitamin D intake. Both vitamin D_2 and D_3 are considered equally beneficial for increasing vitamin D status (50) and supporting health (57). A 2023 systematic literature review identified that a vitamin D_2 intake of 15 µg/day from UV-exposed mushrooms significantly increased serum levels of vitamin D_2 (58), and 50 µg vitamin D_2/day from mushrooms was equivalent to supplements of the same dose of both D_2 and D_3 (5). Thus, ensuring the availability of UV-exposed mushrooms can make an important contribution to increasing vitamin D status and reducing vitamin D deficiency at levels equivalent to current supplementation practices (low dose vitamin D of 1,000 to 2,000 international units).

In the US, vitamin D-enriched or sunlight-exposed mushrooms are readily available for purchase; a collaborative effort between Monterey Mushrooms and the U.S. Department of Agriculture that created mushrooms containing 100% of the Institute of Medicine EAR per 85 g serving (34, 59). In Australia, vitamin D-enriched mushrooms are produced via exposure to UV-lamp pulses (60), though it is not widespread. Given the role that vitamin D-enhanced mushrooms can play in contributing to daily vitamin D requirements, widespread UV exposure of mushroom at the farm or its production warrants consideration.

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Mushrooms are currently not a consideration as a source of vitamin D in dietary guidelines.

While mushrooms naturally contain and can produce significantly increased vitamin D_2, their role in the provision of vitamin D is not recognised within dietary guidelines worldwide. The ADG consider mushrooms within the "vegetables and legumes" core food group, and in the subgroup "other vegetables", alongside salad vegetables such as tomatoes and cucumber (56). While each core food group in the ADG is characterised by a set of essential nutrients provided by that core food group, vitamin D does not feature in any of the food groups. Similarly, mushrooms are classified as "other vegetable" in the Dietary Guidelines for Americans (61), and not specifically mentioned in the New Zealand Eating and Activity Guidelines (62).

Both the ADG and the recent Dietary Guidelines for Americans (3) fail to provide adequate vitamin D (2, 3), indicating that meeting vitamin D needs is difficult and that current eating patterns require additional support to do so. When followed, the dietary patterns in the ADG successfully provide for all nutrient requirements across the lifespan, with the exception of vitamin D for all demographic groups, and iron during pregnancy and lactation.

The modelling underpinning the American Dietary Guidelines explored a range of food fortification options to increase vitamin D levels to the EAR (10 µg/day) or Recommended Dietary Allowance (RDA, 15 µg/day), including increased amounts of vitamin D fortified dairy products, fruit juice, grains, and the inclusion of seafood with the highest quantities of vitamin D (3). The only option that achieved adequate (RDA level) vitamin D intake for all energy requirements was the inclusion of all options. This was deemed unrealistic, as seafood choices included those not normally consumed by Americans (3).

Neither the American nor Australian modelling approaches considered the use of mushrooms as a source of vitamin D. The Australian modelling included mushrooms (as an "other vegetable") at around 2% of total vegetable consumption for adult diets, equivalent to less than 50 g per week and consistent with most recent sales data for mushrooms (63), and well under global intakes of just under 100 g per week per person (64). Future modelling needs to consider UV-exposed mushrooms as a source of vitamin D.

Dietary modelling supports a role for mushrooms as a key dietary vitamin D source.

In 2021, two dietary modelling papers from the USA (65, 66) showed that the daily addition of one 84 gram serve of mushrooms improved nutrient intakes and reduced micronutrient inadequacy, with minimal impacts on energy, carbohydrate, fat, and sodium levels. Diets were constructed from the National Health and Nutrition Examination Survey (NHANES) 2011-2016 (66) usual intakes, as well as the recommended US Department of Agriculture (USDA) Food Patterns, including the US-Style, Mediterranean, and vegetarian dietary patterns (65). The modelling investigated three mushroom scenarios: *A. bisporus*, *P. ostreatus*, or *A. bisporus* mushrooms exposed to UV light and containing 5 µg vitamin D/serve. All three mushrooms increased intake of key nutrients regardless of the dietary pattern analysed, including dietary fibre, copper, potassium, selenium, riboflavin, and niacin, with additional increases in phosphorus, zinc, choline, iron, thiamine, folate, and vitamin B6. Decreases were seen in the percentage of the adult population with intakes below the EAR for copper, phosphorus, selenium, zinc, thiamine, riboflavin, niacin, folate, and vitamin B6. Both *P. ostreatus* and UV-exposed *A. bisporus* mushrooms increased vitamin D intakes, by 8 to 13%, and 67 to 91%, respectively, depending on the baseline diet. UV-exposed *A. bisporus* mushrooms decreased vitamin D inadequacy in the usual US adult diet from 94.9% to 63.6%.

To determine Australian-based outcomes of mushrooms addition to the diet on nutrient intakes, we modelled the effect of classifying mushrooms as another sub-category than within the “other vegetables” sub-category of the ‘vegetables and legumes’ food group. The modelling approach was based on that used for the 2013 revision of the ADG (2) and was performed at the level of Foundation Diets (designed to meet the energy needs of the smallest and most inactive members of a demographic group), for two dietary patterns (omnivore and ovo-lacto vegetarian) and for three demographic groups (adults 19-30 years; men 51-70 years; women over 70 years). The selected diet models were based on those having largest difference in nutritional composition and requirements (19) (see **Box 1**). Vitamin D requirements were based on the adequate intake (AI) and were 5 µg/day for women aged 19 to 30 years, 10 µg/day for men aged 51 to 70 years and 15 µg for women aged over 70 years (67). The number of recommended serves of “other vegetables” within omnivore and ovo-lacto vegetarian dietary patterns per week is 14 and 7, respectively (2). The total nutritional composition of each modelled Foundation diet for each demographic group per week and per day was calculated, as well as the ability of each diet to meet NRVs (AI or RDI, used in place of EAR to meet the nutrient requirements of most individuals within each demographic group (2)).

Methodology. The modelling was carried out over three steps, as shown in **Figure 3.** A modelling database was first created using the nutritional composition of each Foundation Diet for each demographic group provided within the ADG modelling document (2) and supported by AFCD data (4). Next, alternatives to the original “other vegetables” sub-category were created: “other vegetables - no mushrooms” which included the original sub-category group without mushrooms; “mushrooms”, a mushroom-only sub-category; and, “UV-exposed mushrooms”, containing only UV-exposed mushrooms (4). The composition of each new mushrooms sub-category was an average of raw and cooked (no fat included) mushrooms. The “other vegetables – no mushrooms” subcategory was created by subtracting the calculated nutritional composition of mushrooms from the original “other vegetables” subcategory, followed by normalising the relative percentage contribution of all remaining vegetables to equal 100%. One serve was 75 grams, as specified by the ADG (56). Finally, the modelling of mushrooms as a separate sub-category of vegetables was conducted by subtracting the nutritional composition of "other vegetables – mushrooms" from the total nutritional composition of each original Foundation Diet, for each demographic group, and adding back varying serve numbers of each of "other vegetables – no mushrooms" or the mushrooms-only sub-categories ("mushrooms" or "UV-exposed mushrooms"). This was carried out for a weekly diet in the first instance, within division by 7 to achieve a daily diet. Both substitution and addition models were utilised, where each serve of mushrooms was either substituted for or added to the recommended 14 serves of "other vegetables – no mushrooms" on a stepwise basis. The modelling approach was carried out for each of "mushrooms" and "UV-exposed mushrooms".

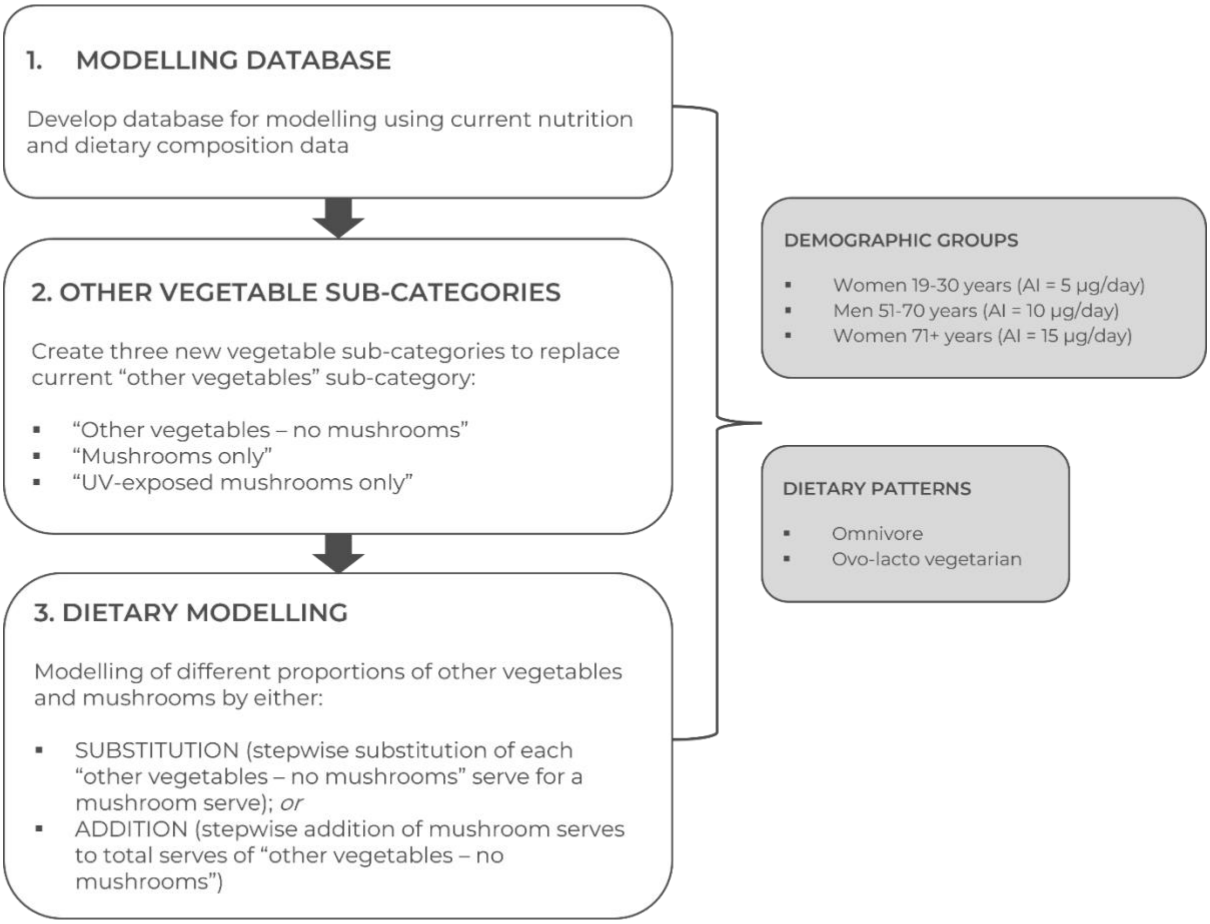


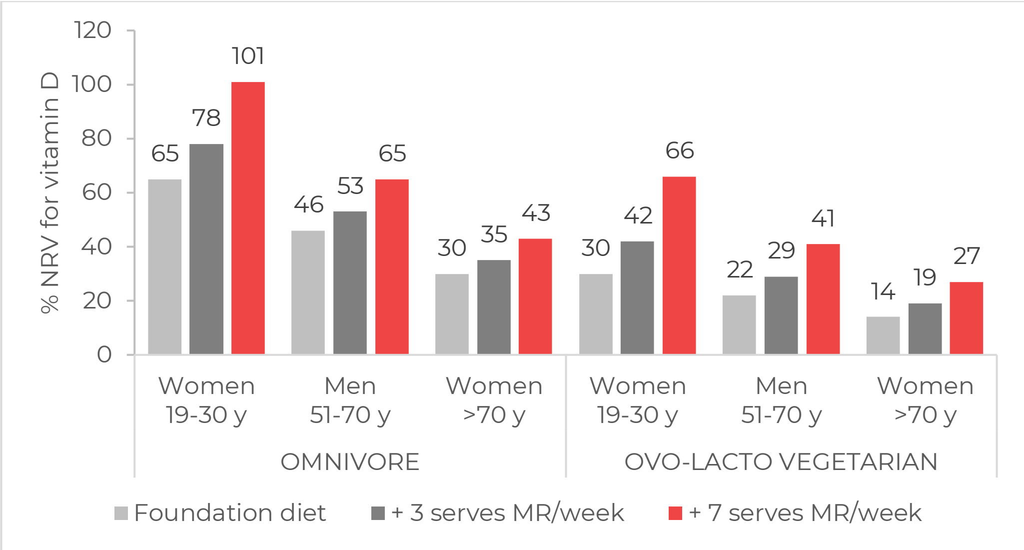
Figure 3. Summary of modelling approach used to estimate the impact of mushrooms as a separate sub-category of vegetables.

Results. Our modelling found that when mushrooms were added as a separate sub-category of vegetables, both mushroom and UV-exposed mushroom sub-categories had notable increases on vitamin D intakes, and several micronutrients, for all demographic groups and both diet models (omnivore and ovo-lacto vegetarian). All original Foundation Diets were inadequate for vitamin D, ranging from 30 to 65% of the AI across demographic groups. The addition of one serve per day of "mushrooms" enabled young women aged 19-30 years following an omnivore diet to meet their recommended dietary vitamin D intakes (AI, 5 µg/day) (**Figure 4A**). While young women on ovo-lacto vegetarian diets, and older adults on both diets, notably increased their vitamin D intakes with one serve per day of "mushrooms", much higher intakes (up to 44 serves per week, data not shown) were needed to meet the applicable AI. However, the theoretical consumption of "UV-exposed mushrooms" resulted in meeting the AI for vitamin D with one serve per week for young women and three serves per week for men 51 to 70 years, regardless of the diet modelled (**Figure 4B**). Women over 70 years required four serves of "UV-exposed mushrooms" to meet the AI for vitamin D (data not shown).

Other micronutrients were positively impacted, with all modelled diets meeting the NRVs for all nutrients for all demographic groups (**Supplementary Table 1**). In omnivore diets, there was an 18.6 to 24.5% increase in the provision of selenium for all demographic groups and a 10% increase in thiamine for women aged over 70 years. Benefits were observed for ovo-lacto vegetarian diets, particularly for selenium intakes, which were inadequate in Foundation Diets. The addition or substitution of one serve/day of "mushrooms" increased selenium intakes from 79.5% of the RDI (in women aged over 70 years) to 120% of the RDI (in women aged 19 to 30 years), where all demographic groups met selenium requirements. Potassium was increased by just over 10% of the AI for both men 51 to 70 years and women aged over 70 years. While there were small decreases in some nutrients, such as riboflavin and vitamin B12, NRVs were still met. There was a negligible impact on sodium, saturated fat, and energy intakes in all modelled diets for all demographic groups, even with the addition of one serve per day of mushrooms in addition to the recommended serves of other vegetables.

Our findings show that mushrooms have the potential to make a meaningful contribution to the vitamin D and micronutrient intakes of Australian adults. Specifically, the addition of one 75 g serve of mushrooms per day, either non-UV or UV-exposed, can make a notable impact on the ability of an individual to meet their vitamin D needs. Mushrooms therefore need to be considered in the context of the Australian dietary guideline recommendations and current inadequate vitamin D intakes. However, the daily consumption of non-UV exposed mushrooms modelled is higher than current intakes, both in Australia (50 g/week) (63) and globally (100 g/week) (64). In contrast, models using UV-exposed mushrooms increased vitamin D intakes at levels similar to current consumption, suggesting that the mass production of UV-exposed mushrooms may offer an effective solution to addressing low vitamin D intakes and inadequacy.

A.



B.

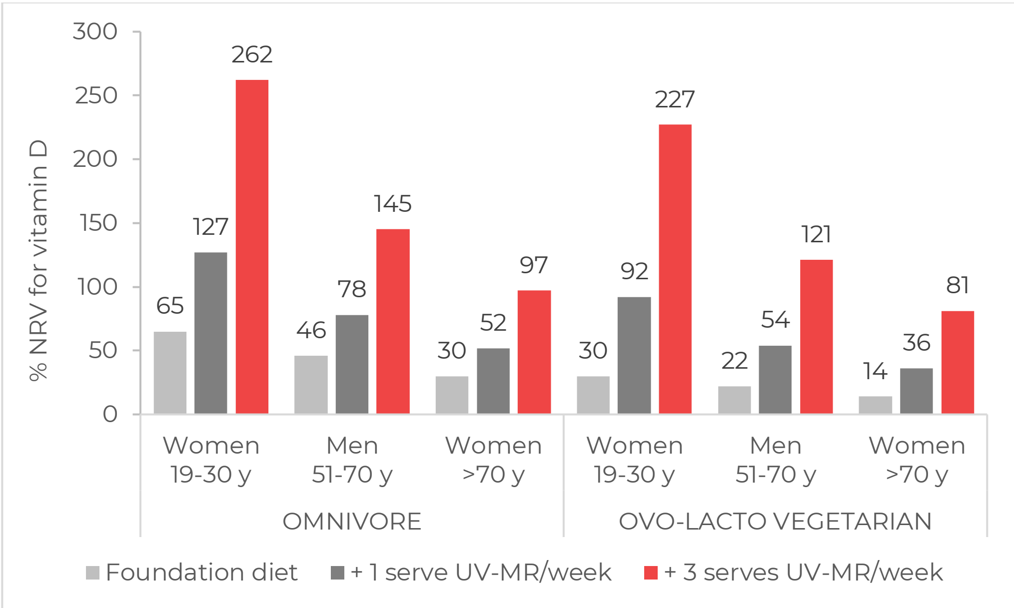


Figure 4. Results of mushroom-centred dietary modelling for vitamin D intake as a percentage of the Nutrient Reference Values for vitamin D for each demographic group. A. non-UV exposed *A. bisporus* mushrooms(MR); B. UV-exposed *A. bisporus* mushrooms (UV-MR). Modelling focused on mushrooms as a separate subcategory of vegetables within Foundation Diets from the Australian Dietary Guidelines. 1 serve = 75g.

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Supplementary Table 1. Full results of the mushroom-centred dietary modelling (one serve per day) for each demographic group and for both omnivore and ovo-lacto vegetarian diets, showing the percentage change in each nutrient compared to the *Foundation Diet* produced by ADG dietary modelling.

NUTRIENT	WOMEN 19-30 YEARS			MEN 51-70 YEARS			WOMEN >70 YEARS		
	FDN DIET	+ MR	% Δ	FDN DIET	+ MR	% Δ	FDN DIET	+ MR	% Δ
Omnivore diet									
Macronutrients									
Energy (kJ)	7384	7461.9	1.05	8286.5	8364	0.94	6586.6	6665.1	1.19
Protein (g)	101.2	103.3	2.08	104.9	107.1	2.10	94.1	96.3	2.34
Carbohydrate, total (g)	206.3	207.9	0.78	214.8	216.3	0.70	169.5	170.9	0.83
Sugars, total (g)	91.1	91.4	0.33	91.9	92.2	0.33	108.2	108.4	0.18
Dietary fibre (g)	34	35.5	4.41	34.4	35.9	4.36	26	27.5	5.77
Fat, total (g)	52.4	52.8	0.76	70.9	71.3	0.56	52.6	53	0.76
SFA, total (g)	17.8	17.9	0.56	21.9	22	0.46	19.1	19.2	0.52
Vitamins									
Thiamin (mg)	1.6	1.6	0.00	1.6	1.7	6.25	1	1.1	**10.00**
Riboflavin (mg)	2.5	2.5	0.00	2.5	2.5	0.00	2.9	2.9	0.00
Niacin equivalents (mg)	51.5	55	6.80	51.8	55.4	6.95	45.8	49.6	8.30
Vitamin B6 (mg)	1.7	1.8	5.88	1.8	1.8	0.00	1.7	1.7	0.00
Folate (DFE) (µg)	496.3	515.2	3.81	494.7	513.5	3.80	512.9	531.8	3.68
Vitamin B12 (µg)	5.9	5.9	0.00	6.2	6.2	0.00	8.1	8.1	0.00
Vitamin A (RE) (µg)	1435.6	1440.2	0.32	1575.8	1578.8	0.19	1366.6	1368.2	0.12
Vitamin C (mg)	125.3	128.3	2.39	129.2	131.4	1.70	122.4	123.4	0.82
Vitamin D (µg)	3.3	5.1	**54.55**	4.6	6.5	**41.30**	4.5	6.5	**44.44**
Vitamin E (mg)	9.1	9.2	1.10	12.8	12.8	0.00	8.7	8.7	0.00
Minerals									
Calcium (mg)	1073.5	1077.8	0.40	1120.9	1125	0.37	1397.7	1401.6	0.28
Iodine (µg)	210.2	210.3	0.05	219.1	219.1	0.00	260.3	260.3	0.00
Iron (mg)	12.2	12.6	3.28	12.3	12.8	4.07	8.6	9	4.65

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NUTRIENT	WOMEN 19-30 YEARS			MEN 51-70 YEARS			WOMEN >70 YEARS		
	FDN DIET	+ MR	% Δ	FDN DIET	+ MR	% Δ	FDN DIET	+ MR	% Δ
Magnesium (mg)	375.1	386.5	3.04	392.3	403.8	2.93	347	358.6	3.34
Phosphorus (mg)	1715.2	1817.5	5.96	1801.8	1907.3	5.86	1776.6	1886.9	6.21
Potassium (mg)	3676.3	4023.9	9.46	3907.9	4263.5	9.10	3845.6	4212.6	9.54
Selenium (µg)	75.2	89.7	**19.28**	81.4	96.5	**18.55**	64.8	80.7	**24.54**
Sodium (mg)	1404.9	1413.85	0.64	1501.9	1511.2	0.62	1178.5	1187.7	0.78
Zinc (mg)	13.8	13.9	0.72	14.1	14.2	0.71	11.9	12	0.84
Ovo-lacto vegetarian diet									
Macronutrients									
Energy, incl, fibre (kJ)	7144.6	7222.58	1.09	8043.3	8121.03	0.97	6391.6	6469.85	1.22
Protein (g)	88.2	90.385	2.48	91.7	93.975	2.48	85.4	87.645	2.63
Carbohydrate, total (g)	186.3	187.68	0.74	211.9	213.33	0.67	162.3	163.71	0.87
Sugars, total (g)	70.8	70.93	0.18	94.3	94.4	0.11	83.1	83.21	0.13
Dietary fibre (g)	48.5	49.9625	3.02	50.5	51.9725	2.92	37.3	38.7625	3.92
Fat, total (g)	57.8	58.1725	0.64	68.3	68.7025	0.59	52	52.3925	0.75
SFA, total (g)	14.2	14.2625	0.44	17.6	17.6725	0.41	15.6	15.6325	0.21
Vitamins									
Thiamin (mg)	2.1	2.17	3.33	2.1	2.2	4.76	1.5	1.56	4.00
Riboflavin (mg)	2.4	2.36	-1.67	2.5	2.49	-0.40	2.6	2.58	-0.77
Niacin equivalents (mg)	43.8	47.54	8.54	46.8	50.62	8.16	40.5	44.44	9.73
Vitamin B6 (mg)	1.7	1.67	-1.76	2	2	0.00	1.5	1.51	0.67
Folate (DFE) (µg)	682.4	701.22	2.76	703.6	722.35	2.66	622.8	641.62	3.02
Vitamin B12 (µg)	3.4	3.39	-0.29	3.7	3.74	1.08	5.3	5.3	0.00
Vitamin A (RE) (µg)	1172.1	1174.42	0.20	1324.3	1325.82	0.11	1080.1	1080.97	0.08
Vitamin C (mg)	83.3	84.77	1.76	128.9	130.07	0.91	83.6	84.12	0.62
Vitamin D (µg)	1.5	3.45	**130.00**	2.2	4.2	**90.91**	2.1	4.15	**97.62**
Vitamin E (mg)	11	11.05	0.45	13.4	13.39	-0.07	8.7	8.67	-0.34
Minerals									
Calcium (mg)	1041	1044.62	0.35	1195.9	1199.4	0.29	1295.2	1298.66	0.27

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NUTRIENT	WOMEN 19-30 YEARS			MEN 51-70 YEARS			WOMEN >70 YEARS		
	FDN DIET	+ MR	% Δ	FDN DIET	+ MR	% Δ	FDN DIET	+ MR	% Δ
Iodine (µg)	173.4	173.43	0.02	198.5	198.49	-0.01	218.1	218.09	0.00
Iron (mg)	17.1	17.56	2.69	16.1	16.58	2.98	12.4	12.85	3.63
Magnesium (mg)	542.4	553.93	2.13	559	570.51	2.06	462.1	473.7	2.51
Phosphorus (mg)	1793	1901.5	6.05	1915.1	2025.27	5.75	1787.2	1899.68	6.29
Potassium (mg)	3520.7	3882.5	**10.28**	4246	4611.87	8.62	3598.7	3970.26	**10.32**
Selenium (µg)	58	73.6	**26.90**	65.4	81.26	**24.25**	47.7	64	**34.17**
Sodium (mg)	1187.6	1196.55	0.75	1341.9	1351.02	0.68	1071.3	1080.37	0.85
Zinc (mg)	12.3	12.39	0.73	12.7	12.73	0.24	11.1	11.2	0.90

Nutrients showing a percentage change of at least 10% are shown in bold.
FDN, foundation; MR, mushrooms; %Δ, percentage change in modelled diet compared to original Foundation diet.

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Mushrooms are more than vitamin D and align with global sustainability efforts.

While mushrooms can address the public health issue of inadequate vitamin D intakes and vitamin D deficiency, mushrooms provide many more essential nutrients, culinary properties, and aligns with plant-based diets. Mushrooms possess a rich and unique nutritional composition, including bioactives, are associated with a number of health outcomes, have culinary properties that enable the reduction of meat and sodium in the diet, and are a model of circular agriculture, which aims to optimise efficient resource management (**Figure 5**).

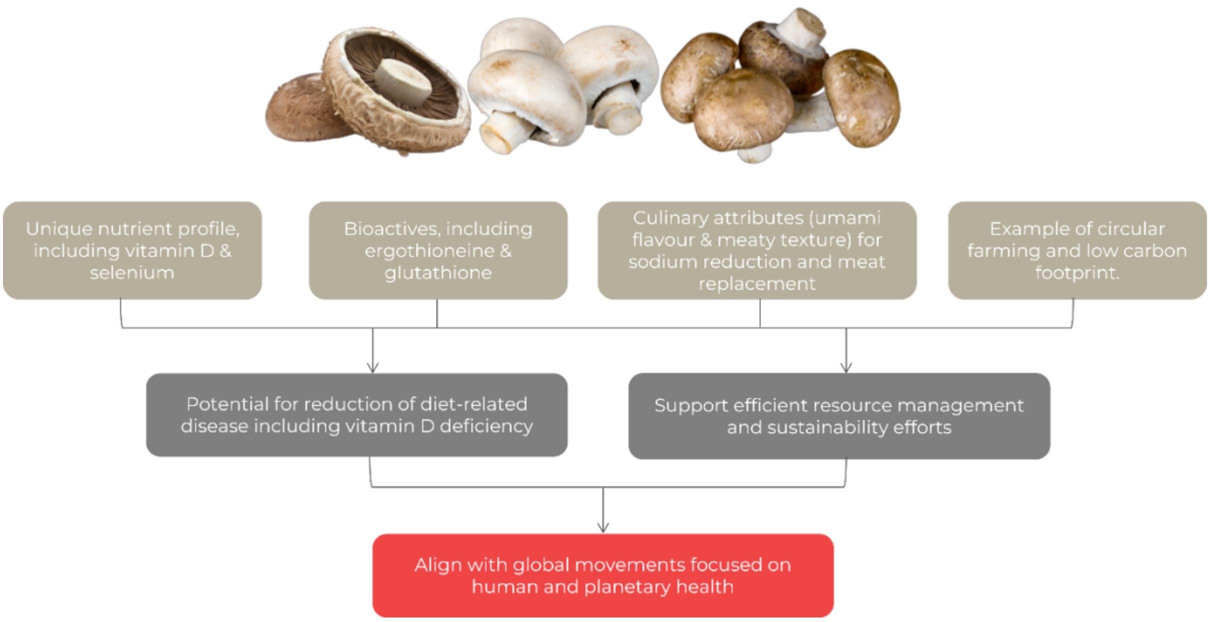

Figure 5. Role of *A. bisporus* mushrooms in supporting both human and planetary health, by providing a unique nutrition, bioactive, and culinary profile, with production via circular farming.

Mushrooms are a source of eight micronutrients in addition to vitamin D, including the B vitamins niacin, pantothenic acid, folate, and biotin, and minerals selenium, copper, phosphorus, and potassium, providing at least 10% of daily requirements in a single serve (4, 67-69). In **Table 2,** we have compared the nutritional profile of mushrooms to the characterising nutrients of each food group in the ADG. Mushroom's nutritional composition does not align with any of the distinguishing nutrients in any of the food groups. While potassium, folate, and vitamin B3 are shared by many of the food groups, no other nutrients provided by mushrooms are included as characterising nutrients. These findings are in contrast to the current classification of mushrooms in the ADG as a vegetable, and specifically as an 'other' vegetable subcategory along with salad vegetables (56). It is also notable that vitamin D is not included as a distinguishing nutrient for any core food group in the ADG and that the Foundation Diet in the ADG is inadequate for vitamin D.

The bioactive composition of mushrooms is important to consider, as some bioctives are unique to mushrooms, and others are found across other food groups. Consistent with their distinct nutrient composition compared to vegetables, mushrooms do not contain carotenoids, a characterising

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bioactive of the vegetables food group, serving as pre-vitamin A in the diet (56). Mushrooms are the richest dietary source of ergothioneine (70) and contain notable amounts of glutathione, beta-glucan, chitin, phytosterols. The combination of ergothioneine and glutathione provided by mushrooms has received particular attention in recent literature, as both have potent antioxidant activity and potentially work in concert (70). Ergothioneine is a sulfur-containing amino acid produced only by fungi and some cyanobacteria and mycobacteria (70) that has anti-inflammatory, antioxidant, and anticancer activity (71). It has been dubbed a "longevity vitamin", with consumption inversely associated with both total mortality and mortality from neurological disorders, and positively associated with longevity (72). Further, it has been proposed to hold therapeutic benefit in the prevention and treatment of COVID-19, especially in the elderly and those with underlying health conditions (73). Low blood or tissue levels of ergothioneine have been associated with several disease states including neurodegenerative disease, kidney disease, diabetes, macular degeneration, and cardiovascular disease (74). There is no frank deficiency with ergothioneine, and hence no recommended intake; however, humans have a dedicated ergothioneine transporter present in many tissues (70), further supporting the importance of ergothioneine for human health. Levels of ergothioneine in mushrooms range from 1 to 26 mg/100 g fresh weight (FW), with *A. bisporus* containing 1-4 mg/100 g FW (51, 70) and the highest levels in enoki and porcini mushrooms (51, 70). Glutathione is an endogenously produced tripeptide considered to be critical for maintaining health and preventing disease (70). Low levels are associated with increased risks for cancer, cardiovascular diseases, arthritis, and diabetes (70). While glutathione is present in a range of foods, particularly fruits and vegetables (75), the combination of ergothioneine and glutathione in mushrooms is unique. This is of particular interest given the suggestion that ergothioneine may help to maintain glutathione levels in the presence of an oxidative burden by interacting with other cellular defence systems (70). The glutathione composition of mushrooms ranges from 3.4 mg/100 g FW (white button, *A. bisporus*) to 15.4 mg/100 g FW (*L. edodes*) (70).

Chitin, the structural component of mushrooms, similar to cellulose in plants, is only otherwise found in crustaceans and insects (76), and is associated with clinical health benefits including prebiotic and cholesterol-lowering effects. Rodent studies have also suggested metabolic, digestive, antiviral, antifungal, and anticancer activity (76). Mushroom beta-glucans are structurally distinct from those found in grains, but similarly provide a range of beneficial health effects. While a recent systematic literature review (SLR) of randomised controlled trials on fungal beta-glucans found that the health-promoting properties are manifested primarily through the potentiation of the immune system (77), potential additional and possibly linked functions include anti-inflammatory, anti-viral, anti-cancer, cholesterol-lowering, and prebiotic activity (78). Mushrooms have high levels of the phytosterol ergosterol, the vitamin D_2 precursor that may also possess cholesterol and blood pressure lowering properties, as well as anti-cancer, anti-inflammatory, and antioxidant activities (79). Finally, a range of additional bioactives have been found in mushrooms, such as flavonoids, phenolic acids, bioactive peptides, polysaccharides, and enzymes, attributed with health-promoting functions that include antioxidant, anti-tumour, anti-hypertensive, anti-fungal, immunomodulatory, antibacterial, antiviral, anti-inflammatory, and hypolipidemic activity (6, 80-87). Select mushroom species (including *A. bisporus*) also contain lovastatin, a compound belonging to the statins group that are commonly used in cholesterol-lowering drugs (88), although research on the bioactivity of lovastatin in mushrooms is limited.

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Table 2. Nutritional composition of mushrooms compared to that of core food groups in the Australian Dietary Guidelines.

NUTRITIONAL COMPONENT	FOOD GROUP[1]					
	MUSHROOMS	VEGETABLES	FRUIT	GRAINS	MILK AND ALTERNATIVES	MEAT AND ALTERNATIVES
Distinguishing nutrients[2]	Copper Phosphorus **Potassium** Selenium **Vitamin B3** Vitamin B5 Biotin **Folate** Vitamin D	Carbohydrate Fibre Iron Magnesium **Potassium** **Folate** Vitamin C	Carbohydrate Fibre **Potassium** Vitamin B6 **Folate** Vitamin C	Energy Protein Carbohydrate Fibre Iodine Iron Magnesium Zinc Vitamin B1 Vitamin B2 **Vitamin B3** **Folate** Vitamin E	Energy Fat Carbohydrate Protein Magnesium **Potassium** Zinc Vitamin A Vitamin B2 Vitamin B12	Energy Protein Omega-3 fatty acids Omega-6 fatty acids Fibre *(plant)* Iron Magnesium Zinc **Potassium** **Vitamin B3** Vitamin B12 *(animal)* Vitamin E
Bioactives[3]	**Ergothioneine** **Glutathione** **Beta-glucan** **Chitin** **Phytosterols** **Polyphenols** **Phenolic acids** **Bioactive peptides**	**Polyphenols** **Glutathione** Carotenoids	**Polyphenols** **Glutathione** Carotenoids	**Beta-glucan**[4] **Phytosterols** **Phenolic acids**	**Bioactive peptides** **Bioactive proteins** **Phytosterols (*plant*)** Beta-carotene	**Chitin** and chitosan **Glutathione** **Bioactive peptides** **Ergothioneine** **Phenolic acids** **Phytosterols** **Polyphenols** Taurine L-carnitine Creatine Coenzyme Q10

Nutritional components in bold are those shared by mushrooms and at least one of the other food groups.

[1] Food groups presented are the core food groups of the Australian Dietary Guidelines (ADG), with the exception of mushrooms, which refers to *A. bisporus* (white/common) mushrooms. The core food groups of the ADG are: Vegetables and legumes/beans (“Vegetables”), Fruit (“Fruit”), Grain (cereal) foods (“Grains”), Milk, yoghurt, cheese, and/or alternatives (“Milk and alternatives”), and Lean meats and poultry, fish, eggs, tofu, nuts and seeds, and legumes/beans (“Meat and alternatives”).

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[2] Nutritional composition was based on the characterising nutrients of each core food group (2, 56)Modelling to inform the Australian Guide to Healthy Eating; 2. Eat for Health, Educators Guide; and the nutritional composition of mushrooms provided by the AFCD. Bioactive composition was sourced from the scientific literature for mushrooms (6, 7, 70, 78-80); Vegetables and fruit (56, 75, 89); Grains (90, 91); Milk and alternatives (92-95); Meat and alternatives (96-101).

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The bioactive composition of mushrooms has been proposed to play a role in multiple beneficial health outcomes associated with mushroom consumption (102). In addition to the ability of UV-exposed mushrooms to significantly increase vitamin D status, mushrooms have been linked to improved immune function and cardiometabolic health, reduced risks for total, breast, and ovarian cancers and all-cause mortality, beneficial changes to the gut microbiota, and decreased appetite and energy intake (5, 58, 102-111). The human evidence underpinning these health benefits is summarised in **Table 3** and includes research showcasing specific outcomes achieved with the partial or full substitution of mushrooms for red meat (105-107), including prebiotic, appetite-related, and cardiovascular effects. The benefits provided by mushrooms have been largely attributed to ergothioneine and glutathione, with oxidative damage known to play a fundamental role in many chronic diseases, as well as the cholesterol-lowering and immunomodulatory properties of beta-glucans (102). However, it is likely that the positive health outcomes seen with mushroom consumption are due to the interaction of the many bioactives and essential nutrients contained within mushrooms, including mechanisms that are yet to be uncovered.

Table 3. Summary of findings for the relationship between mushroom intake and health.

HEALTH OUTCOME	SUMMARY OF FINDINGS	REFERENCES
Vitamin D status	• Intake of vitamin D from UV-treated mushrooms (15 µg/day) can support sufficient vitamin D status. • 50 µg vitamin D_2/day from UV-exposed mushrooms equivalent to supplement in increasing serum vitamin D levels.	(5, 58, 103, 104)
Inflammation and immune function	• 100 g/day fresh *A. bisporus* increased secretory immunoglobulin A levels, indicating a potential benefit for mucosal immunity. • 8 to 16 g/day powdered *A. bisporus* decreased levels of the inflammatory cytokine TNF-α, and increased antioxidant capacity.	(5)
Satiety and energy intake	• 226 g/day fresh *A. bisporus* significantly reduced feelings of hunger and prospective food consumption, and increased feelings of fullness, when compared to isoenergetic quantities of beef. • Mixed effects on energy intake; no effect when substituted for isoenergetic beef but decreasing energy intake when substituted for volume-matched beef.	(5, 106)
Cancer	• Higher mushroom consumption decreased risk for ovarian cancer (by 32%), breast cancer (by 35%), and total cancer (by 34%) vs lower mushroom consumption; total cancer risk was decreased by 45% at a mushroom intake of 18 grams/day . • Levels of the prostate specific antigen (PSA) decreased with a higher (4–14 g extract daily) vs. lower intake of mushrooms indicating lower levels of prostrate growth.	(5, 102)
Gastrointestinal	• Fresh *A. bisporus* mushrooms (226 g/day) increased the ratio of Bacteroidetes to Firmicutes in comparison to red meat.	(5, 105)

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HEALTH OUTCOME	SUMMARY OF FINDINGS	REFERENCES
	• Beneficial effects on stool weight (increase), bowel strain (decrease), and faecal odour and halitosis (decrease).	
Cardiometabolic markers	• Doses from 100 g/day fresh *A. bisporus* mushrooms associated with significantly lower glucose, total cholesterol, low-density lipoprotein, triglycerides and body weight, and higher adiponectin and high-density lipoprotein, vs control. • Consumption of 226 g mushrooms in place of meat for 3 meals/week reduced bodyweight, BMI, waist circumference, percent body fat, blood pressure, and inflammation.	(5, 107, 110, 111)
Mortality	• A 6% decreased risk of all-cause mortality with a higher vs lower consumption of mushrooms in a meta-analysis of prospective cohort studies. • Data from the Third National Health and Nutrition Examination Survey in the US showed a 35% lower risk of all-cause mortality when mushrooms were consumed instead of red or processed meats.	(108-110)

The culinary properties of mushrooms include a meaty texture and an umami flavour, produced by a combination of the naturally present amino acids glutamate and aspartate and 5'-nucleotides (such as 5'-inosinemonophosphate), as well as volatile compounds and other components (7, 8). These culinary properties have additional relevance for health by allowing mushrooms to be used as both a flavour enhancer and partial meat substitute in the diet and food industry applications, reducing the sodium and saturated fat content of a meal, whilst maintaining palatability.

A 2022 scoping review including 52 studies identified that the addition of umami flavour for sodium reduction in foods was both beneficial and acceptable (112). In individual studies specifically investigating the substitution of meat with mushrooms, sensory appeal with up to 80% substitution was consistently shown (113-117), including increases in flavour, even when salt levels were also reduced (115, 117). A 2017 study by Wong *et al* found that consumers preferred the reduced sodium (by 45%) with *A. bisporus* mushroom substitute for meat in a taco filling compared to its full sodium counterpart (117). Mushrooms also out-performed textured soy protein in substituting for meat and lowering sodium content in beef patties (116). In these studies, the substitution of mushrooms for meat was accompanied by a decrease in total energy, saturated fat, and sodium intakes, and increase in fibre and potassium intakes. These findings are of significance given that current intakes of saturated fat and sodium are higher than recommended (56). While protein intake was also reduced, protein is not a nutrient of concern in the Australian population (118). As the unique sensory properties of meat have been identified as key barriers to dietary meat reduction (119), there is a need for meat analogues that are able to mimic the structure, texture, taste and appearance of traditional meat products (119), a demand readily met by mushrooms' unique culinary properties.

Taken together, the evidence shows that mushrooms have significant potential to contribute to efforts to reduce diet-related disease, including use as a partial substitution of mushrooms for meat and in sodium reduction efforts. Further, an area of focus in dietary guidelines worldwide is environmental sustainability, with many guidelines recommending the increase of plant-based foods and a decrease in animal foods and highly processed foods (120).

Although consumer demand for plant-based meat alternatives has increased both globally (119) and in Australia (121), many products are highly processed, can be high in saturated fat and sodium, and may not provide the same nutritional benefits as the whole food from which they were derived (119, 121). A recent cross-sectional study in Australia identified that while plant-based meat alternatives had a higher health star rating (by 1.2 stars) compared to traditional meat products, as well as lower mean saturated fat (by 2.4 g/100 g) and sodium content (by 132 mg/100 g), 84% of meat alternatives were ultra-processed when classified according to the NOVA system (121). In contrast, mushrooms are a whole, unprocessed food with a healthy nutritional profile as well as a notably low environmental impact, largely due to their role in circular agriculture, supporting the growth, maintenance, and remediation of the surrounding environment (122, 123). This role is due to the decomposition metabolic activity of mushrooms, which also underpins their importance in the ecosystem, with roles that include (but are not limited to) the interconnection of biological and ecological organisation to support correct ecosystem functioning, and the interaction with both macro- and micro-organisms to create evolutionary links between them (124). In circular agriculture, outputs from plant and animal farm waste are used as inputs in mushroom growing, and spent mushroom waste is then used to produce high-quality compost, animal feed, biofuel, and for bioremediation, (122, 123). Mushrooms have a much lower carbon footprint than that of meats (9), indicating that the substitution of meat for mushrooms holds weight both nutritionally and environmentally.

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Conclusions and Call to Action: Promoting mushrooms as part of the solution to vitamin D deficiency.

Mushrooms have a unique nutrient, bioactive, and culinary profile with a large body of evidence showing that they can make a significant contribution to dietary intakes and the reduction of diet-related diseases. They are a meaningful yet currently undervalued source of vitamin D, a key nutrient of public health concern in Australia and globally. Mushrooms (particularly UV-exposed) offer a unique and untapped solution to improving vitamin D intakes that also improves overall nutrient intakes and supports environmental sustainability. Current worldwide dietary recommendations and guidelines are increasingly focused on environmental sustainability and a movement towards "plant-based" diets. While possessing numerous benefits, plant-based dietary guidelines may inadvertently increase vitamin D deficiency and inadequate intakes of other predominantly animal-derived nutrients such as selenium.

There is an opportunity for health professionals, stakeholders, and policy makers to address vitamin D deficiency by providing greater guidance on maximising diet as a key source of vitamin D, by both UV-exposing mushrooms and giving greater focus to mushrooms in dietary recommendations. A key mode to provide this information is within government-directed dietary guidelines, both in Australia and globally, in a way that recognises the unique nutritional, culinary, and environmental attribute of mushrooms, with practical advice for their inclusion in the diet. For example, moving mushrooms into a new sub-category of the vegetables core food group, as modelled, could better facilitate an increase in mushroom intake. To further support this, practical guidance for how to use mushrooms can be provided, such as purchasing UV-exposed mushrooms or putting mushrooms in the sun prior to eating to produce the recommended daily vitamin D requirements (for example, sun-expose for 15 minutes any time between 10 am and 3 pm, and store in fridge for up to 8 days (46)), as well as recipes and cooking instructions on partially substituting mushroom for minced or ground beef in popular recipes (such as Spaghetti Bolognese, burger patties, taco filling, and so on).

UV-exposed mushrooms produce substantial increases in vitamin D intake and status in the same way and level as supplemental vitamin D. Yet, the production of UV-exposed mushrooms is limited and comes at a cost to farmers and consumers, creating a barrier for its inclusion. Governmental action in supporting the universal UV-exposure of mushrooms, similarly to efforts in the universal iodisation of salt (125), could enhance efforts to address vitamin D deficiency.

In conclusion, the unique contribution of mushrooms to solving vitamin D inadequacies globally and its contribution to both human and planetary health is currently unrealised and under-appreciated. Mushrooms are a natural and non-animal source of vitamin D in the diet, with the potential to make a meaningful impact not only on vitamin D deficiency rates and health, but on at-risk nutrients and health-associated bioactives.

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