



# What are the health benefits and bioactive components found in *Agaricus bisporus* mushrooms?

Key findings from a world-first systematic literature review

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Prepared by Nutrition Research Australia Pty Ltd.

# Executive Summary

This is the first ever systematic review on the health benefits of the world's most commonly consumed mushroom, *Agaricus bisporus*. This is also the first systematic review to explore the amount of key bioactive compounds found in *Agaricus bisporus*, which may explain the reported effects of mushrooms on health.

## **Eating *Agaricus bisporus* can:**

- Increase and maintain vitamin D levels
- Reduce inflammation
- Increase fullness and reduce hunger
- Improve gut health
- Lower the risk of ovarian and prostate cancer
- Improve metabolic markers
- Strengthen the immune system

## ***Agaricus bisporus* contains:**

- Antioxidants usually reported as flavonoids
- Ergosterol, which converts to vitamin D with ultraviolet (UV) light
- Ergothioneine, a powerful antioxidant
- More beta-glucans than oats
- Chitin, a naturally occurring fibre

## **The Bottom Line**

*Agaricus bisporus* contains beta-glucans, ergosterol, ergothioneine, vitamin D, and unknown antioxidants usually reported as flavonoids. The amount of these nutrients can differ depending on the type of mushroom, cooking method, cooking length and part of the mushroom. Eating UV-exposed mushrooms is just as effective as taking a vitamin D supplement to increase and maintain a person's vitamin D levels. *Agaricus bisporus* can reduce the risk of some cancers, and improve metabolic health, immune function, and gastrointestinal function. Future research opportunities have been identified.

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# Background

Although commonly regarded and consumed as a vegetable, mushrooms are members of the *Fungi* kingdom and offer a unique nutritional profile. Fungi are biologically different to both plants and animals, and for this reason, are rich in nutrients that are normally found in vegetables, meats and grains. There is a growing body of evidence that suggests consuming several mushroom species, either as a food or as extracts, may improve physical and mental health. Research from laboratory experiments and those conducted in animals report that eating edible mushrooms can improve health. These studies show that mushrooms, of varying types, are a rich source of bioactive compounds including ergothioneine, ergosterol, vitamin D, beta-glucan and selenium, which can:

- Strengthen the immune system
- Help control blood sugar levels, cholesterol, and blood pressure
- Help manage body weight
- Improve gut health
- Promote strong bones
- Improve brain function

**However, it is unknown whether similar effects also occur in humans.**

There is also a large variety of mushrooms on the market today. The mushrooms most commonly eaten by humans worldwide belong to the *Agaricus bisporus* species, which includes white button, brown button, portobello, and cremini mushrooms. **This is the first ever systematic review conducted on the effects of the world's most commonly consumed mushroom, *Agaricus bisporus*, on human health outcomes, and also the first ever to explore which bioactive compounds are present in them.**

# What was done

A systematic literature search of five scientific electronic databases (MEDLINE, EMBASE, Scopus, CINHALL, and The Cochrane Library) was conducted. There were no restrictions were placed on the search, such as the type of study that could be included or the date when it was published.

The purpose of this review was to synthesize the evidence on *Agaricus bisporus* mushrooms to

- (i) examine its effect on human health outcomes; and
- (ii) determine the amount of bioactive compounds that explain their health effects.

To be included in this review, a study needed to meet the following criteria:

- ✓ Be conducted in humans of any age;
- ✓ Use *Agaricus bisporus* in whole or processed (e.g. dried extract) form; and
- ✓ Report effects on any health outcome or;
- ✓ Report on one or more of the following bioactive compounds: ergosterol, ergothioneine, vitamin D, flavonoids, glucans, and/or chitin.

A total of 9,811 studies were found, and of these, 501 studies were on *Agaricus bisporus* specifically. These 501 studies represent a **complete and up-to-date database** of every study published on the *Agaricus bisporus* mushroom and health related outcome or nutritional/bioactive compound in the world. It includes studies in humans, but also animal and cell line studies. The evidence is current to December 2019 and is being continuously monitored and updated with newly published papers during the course of this project.

Of the 501 studies which investigated *Agaricus bisporus*, a total of 68 studies met the eligibility criteria for the review and were included in this review. Fifteen studies reported the effect of mushroom consumption on human health, and 53 studies reported the amount of one or more bioactive compounds.

# What was found

## The health effects reported in the studies were on:

- ✓ Vitamin D absorption (**4 studies**)
- ✓ Inflammation (e.g. cytokines, antioxidant capacities; **3 studies**)
- ✓ Satiety (e.g. hunger and fullness; **2 studies**)
- ✓ Gut health (e.g. microbiota, stool weight, bowel strain, faecal odour, bad breath; **2 studies**)
- ✓ Cancer (**2 studies**)
- ✓ Cardio-metabolic markers (e.g. glucose, cholesterol, triglycerides, body weight; **2 studies**)
- ✓ Immune function (**1 study**)

Most of the research (80% of studies) was of medium to high methodological quality, predominantly conducted in the USA (67%) and among healthy individuals (57%). None of the studies reported an adverse effect from eating the mushrooms.

## We found that eating *Agaricus bisporus* can:

- ✓ Increase and maintain vitamin D levels
- ✓ *Reduce inflammation*
- ✓ *Increase satiety (feeling of fullness)*
- ✓ *Improve gut health*
- ✓ *Lower the risk of some cancers*
- ✓ *Improve metabolic markers*
- ✓ *Strengthen the immune system*

### *Increase and maintain vitamin D levels*

- The strongest evidence of any health benefit was for improving vitamin D levels.
- All studies showed that UVB-exposed mushrooms increase vitamin D<sub>2</sub> levels.
- Eating UVB-exposed mushrooms was as effective at increasing total vitamin D levels as taking a vitamin D supplement/pill.

### *Reduce inflammation*

- Cooking mushrooms increases its antioxidant content and activity
  - Cooking mushrooms (100g per day or 5 button mushrooms) increased both ergothioneine (an antioxidant) and increased oxygen radical absorbance capacity (antioxidant activity) in a high quality randomised controlled trial.
- Eating a mushroom extract high in alpha-glucans (starch) decreases some inflammatory markers
  - Eating 5g per day of alpha-glucans (starch) from a mushroom extract over 5 weeks led to a decrease in tumour necrosis factor (TNF)-alpha (a pro-inflammatory cytokine), compared to the control.
  - No effects were found on other inflammatory markers measured (e.g. interleukin (IL)-1 $\beta$ , IL-2, IL-4, IL-6, IL-10, IL-12, IL-13, IL-17, interferon- $\gamma$ , serum creatinine).

### *Increase satiety (feeling of fullness)*

- Eating mushrooms was associated with increased feelings of fullness, reduced hunger, and a lower food intake during the rest of the day, compared with a protein-matched beef meal without mushrooms.
- No differences in hunger or fullness were found when a mushroom meal was compared to a volume-matched, rather than calorie matched beef meal, but total calorie intake was much lower.

### *Improve gut health*

- Mushrooms (either fresh or extract) increased faecal stool weight, reduced strain during bowel movements, reduced faecal odour, improved gut microbiota, and minimised bad breath, compared to the control.
- No changes were found in markers of bacterial fermentation (breath H<sub>2</sub>, faecal pH and faecal short chain fatty acids) or bowel regularity, compared to the control.

### *Lower the risk of some cancers*

- Regularly consuming mushrooms reduced the risk of ovarian and prostate cancers.
- Eating more than 2g per day of white button mushrooms was associated with a 32% reduced risk of ovarian cancer.

- Mushroom extract was associated with decreased prostate specific antigen levels in 36% of prostate cancer patients. Prostate specific antigen levels are used by doctors to help detect prostate cancer or other prostate abnormalities.

*Improve metabolic markers*

- Levels of adiponectin increased after eating 100g of cooked white button mushrooms daily over 16 weeks.
- Eating white button mushrooms cooked in olive oil (2g/kg body weight/day) for 30 days were associated with lower glucose, total cholesterol, low-density lipoprotein, triglycerides, and body weight, and higher high-density lipoprotein, compared to the control.

*Strengthen the immune system*

- Compared to usual diet, eating 100g of cooked white button mushrooms for 7 days was associated with increased serum IgA osmolarity, secretion rate, and concentration, which are markers of immune function.
- Findings show that white button mushrooms may improve mucosal immunity. The mucosal immune system protects the body from pathogens than can enter the body’s surfaces through gas exchange (lungs), food absorption (the gut), sensory activities (eyes, nose, mouth, throat), and reproduction (uterus and vagina).

**The key bioactive compounds reported in the studies were:**

Flavonoids (22 studies)	Flavonoids are powerful antioxidants with anti-inflammatory and immune system benefits. Diets that include lots of flavonoid-containing foods are sometimes associated with cancer, neurodegenerative and cardiovascular disease prevention.
Ergosterol (16 studies)	Ergosterol is also called provitamin D <sub>2</sub> . It is found only in fungi and is chemically related to cholesterol. Ergosterol is converted by ultraviolet light into vitamin D <sub>2</sub> , the form of vitamin D that comes from plants and fungi.
Vitamin D (5 studies)	A vitamin essential for bone, muscles and overall health. It also implicated in the prevention of many chronic diseases such as cardiovascular disease, diabetes, cancers, autoimmune diseases, infectious diseases.



Ergothioneine (4 studies)	An amino acid that has important antioxidant properties. Ergothioneine is used in the treatment of liver damage, cataracts, Alzheimer's disease, diabetes, heart disease, and to reduce the signs of aging.
Glucans (9 studies)	A form of soluble dietary fibre that is strongly linked to improving cholesterol levels and boosting heart health.
Chitin (7 studies)	A naturally occurring fibre that is similar to cellulose.

We found that *Agaricus bisporus* contains:

- ✓ An antioxidant compound usually reported as flavonoids
- ✓ Ergosterol
- ✓ Vitamin D
- ✓ Ergothioneine
- ✓ Glucans
- ✓ Chitin

The concentration of these bioactive compounds varied depending on the type of mushroom, the cooking method used and the length of time it was cooked for as well as the amount of UVB exposure. Most of the research uses cultivated white button mushrooms from Europe or Asia.

### Flavonoids

- The greatest concentration of flavonoids was catechin (~396ug/g), followed by myricetin (11.75ug/g).
- Raw is best for flavonoid content.
  - Cooking decreased flavonoid concentration.
  - The greater the cooking time, the greater was the loss.
- The cap is a richer source of flavonoids than the stipe.
  - Approximately 28% greater in cap of white button mushrooms.

### Ergosterol and vitamin D

- Exposing mushrooms to UVB (e.g. in a lab or sunlight) after harvesting increased vitamin D content and consequently decreased ergosterol content (the vitamin D precursor that gets converted to vitamin D with UVB exposure).

- Ergosterol is highest in brown button and cremini mushrooms compared to white button mushrooms.
- There's more ergosterol in the cap of Portobello mushrooms compared to the cap of white button mushrooms.
- No study has ever tested the effect of a cooking method or mushroom maturity on the amount of ergosterol.

### *Ergothioneine*

- There's more ergothioneine in a white button mushroom extract compared to a brown button mushroom extract.
- No study has tested the effect of cooking method or mushroom part (cap or stipe) on ergothioneine content.

### *Glucans*

- Mushrooms contain two main types of glucans (alpha and beta).
  - Beta-glucans, which account for approximately 75% of total glucan concentrations.
- There are more glucans in the stipe than the cap of the mushroom.
- There is approximately 8-12g of beta-glucans in mushrooms [8-9g/100g cap; 10-12g/100g stipe],
  - **Mushrooms have up to 4 times more beta-glucans than oats (3-8g/100g)**, which have been shown to lower cholesterol.
- There are slightly more total glucans in brown vs. white button mushrooms.
- Cooking method or mushroom maturity does not seem to affect beta-glucan content.

### *Chitin*

- Cooking increases chitin, regardless of how the mushroom is prepared and stored (e.g. fresh, frozen or canned).

# Further research opportunities identified

## Clinical trials

- ✓ *Conduct a randomised controlled trial to investigate the cholesterol lowering effect of beta-glucans in mushrooms: Are mushrooms as effective as oats?*
- ✓ *Conduct a randomised controlled trial of the effect of sun exposed mushrooms on vitamin D within the Australian context.*
- ✓ *Conduct a clinical trial of the effect of sun exposed mushrooms on vitamin D status in vulnerable population groups.*
- ✓ *Conduct further randomised controlled trials to strengthen the link between mushrooms and each of the following key health outcomes: immune function, gastrointestinal health, cancer, inflammation and metabolic syndrome.*
- ✓ *Conduct a pilot trial to replicate the findings from non-human studies that show mushrooms improve mental health and cognitive function, as none have been conducted in humans.*

## Bioactive content

- ✓ *Examine different types of cooking methods and the effects they have on mushroom flavour and texture profile.*
- ✓ *Deep dive into umami and combining foods to help inform culinary professionals.*
- ✓ *Measure the time-exposure relationship for vitamin D in *Agaricus bisporus* mushrooms (gills exposed/cap exposed/sliced) for 10- or 15-minute intervals in the Australian sun.*
- ✓ *Measure the concentration of bioactive compounds in Australian mushrooms.*
- ✓ *Test the effect of cooking method and duration on ergosterol concentrations.*

## Communication opportunities

- ✓ *Create a Practice-based Evidence in Nutrition (PEN) professional resource*
- ✓ *Deep dive into umami and combining foods to help inform culinary professionals*
- ✓ *Do an updated analysis of the bioactive and nutrient composition of Australian *Agaricus bisporus* mushrooms, similar to what has recently been completed for potatoes*
- ✓ *Determine if your genes influence whether you like or dislike mushrooms?*
- ✓ *Beta-glucan FSANZ regulation submission*
- ✓ *Vitamin D FSANZ regulation change submission*

# Detailed information on future research opportunities

*Conduct a randomised controlled trial to investigate the cholesterol lowering effect of beta-glucans in mushrooms: Are mushrooms as effective as oats?*

**Background:** Mushrooms contain a substantially higher concentration of beta-glucans compared to oats, rye, and barley. FSANZ and other international food governing bodies have approved a high-level health claim based on the link between eating 3g of beta-glucans (from oats or barley) and blood cholesterol. However, no claim has been approved for mushrooms.

**What is required:** The higher amounts of beta-glucans in mushrooms, compared to oats and barley, present an exciting opportunity to confirm the health effects induced by beta-glucans in mushrooms using a clinical trial.

**Benefit:** This could help to provide the evidence required to support the submission for a health claim for the ability of mushrooms to lower cholesterol.

*Conduct a randomised controlled trial of the effect of sun exposed mushrooms on vitamin D within the Australian context.*

**Background:** This systematic review found the strongest evidence of a health effect for UVB-exposed mushrooms on the improvement of vitamin D status. However, no study has investigated this relationship in the Australian population. Due to the Earth's orbit, Australians are exposed to up to 15% more ultraviolet (UV) radiation than Europeans during summer, and some of the highest levels of UV radiation in the world during the year because of our close proximity to the equator.

**What is required:** Conducting the same study in Australia to test whether we find different results.

**Benefit:** Finding out whether stronger health effects can be achieved from mushrooms that are exposed to higher levels of UV radiation from the Australian sun will give us the direct evidence needed to support a health claim for mushroom's and the improvement of vitamin D in Australia.

*Conduct a clinical trial of the effect of sun exposed mushrooms on vitamin D status in vulnerable population groups*

**Background:** In Australia, 98% of bariatric surgery patients are deficient in vitamin D before they have surgery, cancer patients are advised to avoid sun exposure during chemotherapy and in aged care there is a strong push to avoid medicalisation and focus on food and quality of life, despite a high rate of vitamin D deficiency.

**What is required:** Replicate the randomised controlled trial mentioned above in vulnerable groups of people who are at high risk of vitamin D deficiency (e.g. bariatric surgery patients, cancer patients and the elderly in aged care)

**Benefit:** Findings would be of high clinical relevance.

*Conduct further randomised controlled trials to strengthen the link between mushrooms and each of the following key health outcomes: immune function, gastrointestinal health, cancer, inflammation and metabolic syndrome*

**Background:** This review found that only a small number of studies have looked at the effect of eating *Agaricus bisporus* on each health outcome (1-4 studies for each health outcome). This lack of replication in studies lowers the confidence, or strength of the evidence, for each key result.

**What is required:** Similar studies to be conducted in different groups of people (e.g. the elderly, children, specific disease states).

**Benefit:** Findings can be translated into clinical practice guidelines and public health initiatives.

*Conduct a pilot trial to replicate the findings from non-human studies that show mushrooms improve mental health and cognitive function, as none have been conducted in humans*

**Background:** Decline in brain function during normal aging is partly due to the long-term effects of oxidative stress and inflammation. *Agaricus bisporus* mushrooms possess antioxidant and anti-inflammatory properties that, when given to rats, have produced improvements in both balance and working memory. However, no studies have examined the link between mushrooms and cognitive function in humans.

**What is required:** Conduct a pilot trial to determine whether or not *Agaricus bisporus* consumption can benefit cognitive function and mental health in the wider population.

**Benefit:** Findings would provide support for a clinical trial in this area.

*Examine different types of cooking methods and the effects they have on mushroom flavour and texture profile.*

**Background:** The effect of different types of cooking methods on mushroom flavour and texture profile remains unknown.

**What is required:** Understand these effects through new research.

**Benefit:** Will enhance the culinary versatility of mushrooms and provide exciting new ways for health professionals to promote the use of mushrooms to their clients.

*Deep dive into umami and combining foods to help inform culinary professionals.*

**Background:** Research that explains what happens when umami foods are combined is needed to understand the full potential of this flavour profile. Umami, as a fifth taste, can elevate food by providing richness and complexity while increasing satiety. Umami-rich foods bring a meaty and salty essence to plant-based and low sodium dishes, while they can further enhance digestion and stimulate saliva and digestive juices.

**What is required:** Understand the science behind this unique flavour profile and especially how mushrooms can be combined with other umami-rich foods to increase their flavour and digestive properties.

**Benefit:** This research would significantly enhance the education of culinary professionals and introduce them to new and innovative ways to use mushrooms in their dishes.

*Measure the time-exposure relationship for vitamin D in Agaricus bisporus mushrooms (gills exposed/cap exposed/sliced) for 10- or 15-minute intervals in the Australian sun.*

**Background:** The amount of vitamin D that mushrooms can absorb from the Australian sun is unknown. For example, we don't understand what happens to vitamin D concentrations when you accidentally leave your mushrooms out in the sun for an extended period of time. Also, do differences exist in the vitamin D content of UV-exposed mushrooms depending on how they are placed outside (e.g. gills exposed, or cap exposed) or whether they are sliced?

**What is required:** Conduct a study that measures the vitamin D content of three different groups of UV-exposed mushrooms (e.g. group 1: gills exposed; group 2: cap exposed; group 3 sliced) at 10- or 15-minute intervals over 8 hours.

**Benefit:** Will help us answer to these questions and provide data to inform clinical practice guidelines for the use of mushrooms to treat vitamin D deficiency in Australia.

*Do an updated analysis of the bioactive and nutrient composition using Australian Agaricus bisporus mushrooms, similar to what has recently been completed for potatoes.*

**Background:** FSANZ has recently undertaken a small analytical program to update their food composition data holdings. Foods were chosen if they had either no data, or if data were outdated and no longer reflected the products available for consumption. Vegetables that have recently been updated are cauliflower, carrot, corn and potatoes. Differences in nutrient composition were found for some vegetables (e.g. potatoes) which has led FSANZ to refine their records and results will also feed into future releases of the FSANZ reference database: the Australian Food Composition Database.

**What is required:** An updated nutrient analysis of mushrooms consumed in Australian. Such an analysis has not been completed.

**Benefit:** Could potentially fill some important data gaps and provide an improved level of confidence about the nutrient composition of mushrooms consumed in Australia.

*Test the effect of cooking method and duration on ergosterol concentrations*

**Background:** Ergosterol is an antioxidant compound found in mushrooms that converts to vitamin D<sub>2</sub> when exposed to UV light. Research shows the concentration of some antioxidants found in mushrooms are affected by cooking time and cooking method. For example, the concentration of antioxidants commonly reported as flavonoids decrease with cooking (the greater the cooking, the greater the loss) and microwaving retained the least antioxidants compared to other cooking methods. However, no study has investigated the effect of cooking method on ergosterol concentrations.

**What is required:** Conduct a study to determine the optimal cooking system (method and duration) that results in the highest retention of ergosterol in *Agaricus bisporus*.

**Benefit:** Findings will fill some important data gaps and may have important implications for the vitamin D content of cooked UV-exposed mushrooms.

*Create a Practice-based Evidence in Nutrition (PEN) professional resource.*

**Background:** The PEN System is an online tool that gives nutrition professionals worldwide access to a trusted source of evidence-based information that they can use to improve their practice. PEN has partnered with the Dietitians Association of Australia, Dietitians of Canada, and the British Dietetic Association.

**What is required:** To create a PEN guideline for mushrooms we will need to apply either (i) the Grading of Recommendations Assessment, Development and Evaluation (GRADE)

approach to the key findings of this systematic review, or (ii) apply the PEN System Evidence-based Process (i.e. non-GRADE approach) to grade the levels of evidence, similar to the NHMRC levels of evidence process. This is a PEN requirement.

**Benefit:** Creating a PEN professional resource that focuses on the health benefits of *Agaricus bisporus* mushrooms with help promote the key results from this review to a wide audience of nutrition professionals globally through the PEN platform.

#### *Determine if your genes influence whether you like or dislike mushrooms?*

**Background:** We don't know if taste preferences for umami foods, like mushrooms, are influenced by genetics. Research shows that there are genes related to taste sensitivity (our likes or dislikes to bitter, sweet, umami and even fat flavours). In particular, vegetable preferences are strongly influenced by genetics. However, very few genetic studies have looked at specific foods and results have not been consistent. For some tastes (e.g. sweet, salty and fat) research shows genes partially control our preferences to these foods, this means our preferences for these foods could be modified based on diet.

**What is required:** Undertake research to understand if a consumer's preference to mushrooms could be modified by environmental exposures.

**Benefit:** Will provide important insight when strategising ways to increase consumer intakes.

#### *Beta-glucan FSANZ regulation submission*

**Background:** The Food Standards Code currently permits a high level health claim to be based on the relationship between beta-glucan (from oats and barley) and blood cholesterol. *Agaricus bisporus* mushrooms have four times more beta-glucans than oats.

**What is required:** After conducting a randomised controlled trial to investigate the cholesterol lowering effect of beta-glucans in mushrooms (see details information about this opportunity above), use this evidence to submit an online application to change the Food Standards Code to include a high level health claim for mushrooms.

**Benefit:** *Agaricus bisporus* mushrooms can be marketed and sold with this health claim.

#### *Vitamin D FSANZ regulation change submission*

**Background:** The Food Standards Code specifies the type of vitamin D that is eligible for nutrient content and health claims, and currently the Code only specifies vitamin D3 (cholecalciferol). Vitamin D2, the form of vitamin D in mushrooms, is not eligible. This



currently makes claims about the vitamin D content of mushrooms (beyond basic “source of” claims) difficult.

**What is required:** Apply to amend the Food Standards Code for nutrient content claims, recommending for the Code to be inclusive of vitamin D2.

**Benefit:** Would allow more claims on the vitamin D content of mushrooms to be made, including more nutrient content claims (e.g. “good source of vitamin D”) and general level health claims (e.g. “mushrooms contain vitamin D2, which supports bone health”).