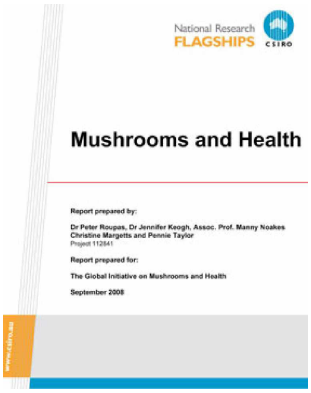

Scientific Investigation from Mushrooms and Health 2008

Executive Summary, Introduction & Methodology

Executive Summary

Mushroom consumption and human health

- Mushrooms belong to the biological classification of *fungi*, but are generally considered in nutrition guides as a vegetable. Cultivated mushrooms (e.g. *Agaricus bisporus*/white, *Agaricus bisporus*/brown, *Lentinus edodes, Pleurotus ostreatus* and others) are a valuable source of several micronutrients and are a low kilojoule/calorie, nutrient-dense food. Mushrooms are low in sodium and high in glutamate which makes them a useful flavour addition to a low-salt diet. As they are low in kilojoules, they are ideal for incorporation in weight loss programs.

- Mushrooms provide 29% of the Recommended Dietary Intake (RDI) for vitamin B2 (riboflavin) and 27% of the RDI for niacin and are one of the very few foods that provide a natural source of vitamin D. Biosynthesis of vitamin D levels from ergosterols in mushrooms can be significantly enhanced by exposure to sunlight or ultraviolet light post-harvest (e.g. during drying).Vitamin D is an important factor for immune function.

- Compared with vegetables, mushrooms are a good source (>10% RDI) of many mineral elements such as potassium, phosphorus, zinc, selenium and copper. *Agaricus bisporus*/brown and other

varieties have been shown to contain high amounts of selenium, although this is dependent on the growing medium. Addition of sodium selenite to the growth substrate has been shown to predictably enrich mushrooms with selenium.

- Although there are very few direct intervention trials, trials on the safety of mushroom consumption in humans indicate that mushrooms and their extracts are generally well-tolerated with few, if any, side-effects. Studies in humans have shown an increase in the antioxidant capacity in urine and no evidence of liver, renal or DNA toxicity, and no clinical problems with regard to blood test results, liver and renal function, glucose and lipid metabolism, or blood pressure. Mushroom components/extracts have had stronger health effects/benefits than whole mushrooms in the limited number of direct human trials to date.

- Immuno-modulating and anti-tumour effects of mushrooms and their extracts appear to hold potential health benefits. These benefits are primarily due to their polysaccharide content, either in the form of beta-glucans or polysaccharide-protein complexes.

- Anti-tumour effects, primarily in human cell lines, have been reported from polysaccharides extracted from a variety of mushrooms. The polysaccharides belong to the beta-glucan family of compounds and appear to exert their anti-tumourigenic effects via enhancement of cellular immunity e.g. via activation of T helper cells and induction of the production of interferon (IFN)-gamma and certain interleukins.

- Anti-tumour effects of proteoglycan fractions from a variety of mushrooms, including *Agaricus bisporus*, involve the elevation of natural killer (NK) cell numbers and the stimulation of inducible nitric oxide synthase gene expression, which is then followed by nitric oxide production in macrophages via activation of the transcription factor, NF-kappaB. Activation of NK cells is likely via interferon-gamma and interleukin mediated pathways.

- Mushroom lectins have been reported to be immuno-modulatory proteins. They have been demonstrated to have thermal/freezing resistance, acid/alkali tolerance and dehydration stable properties suggesting that they would be stable during food processing applications and therefore suitable for functional food/health utilization.

- A lectin from *Agaricus bisporus* appears to be a reversible non-cytotoxic inhibitor of epithelial cell proliferation (colon cancer and breast cancer cell lines). The reversibility of the anti-proliferative effect of the lectin is associated with its release from cancer cells after internalization. The internalization and subsequent slow release, with little degradation of the lectin, reflects the tendency of lectins to resist biodegradation.

- Lectins from *Agaricus bisporus* and a number of other mushrooms have been shown to inhibit human immunodeficiency virus type 1 (HIV-1) reverse transcriptase, an enzyme of paramount importance to the life cycle of the human immunodeficiency virus. A polysaccharopeptide from *Trametes* (*Coriolus*) *versicolor* also has a similar effect on HIV-1 reverse transcriptase.

- Some mushrooms (e.g. Shiitake, *Lentinus edodes*) possess anti-microbial properties, demonstrated *in vitro*, which appear to involve the native immune system, via enhancement of the level of cytokines.

- Exopolysaccharides produced by some mushrooms have been shown to have anti-diabetogenic effects e.g. lowering of plasma glucose, triglycerides, low-density lipoprotein (LDL) and total liver cholesterol in diabetic animal models. The hypoglycaemic effect and improved insulin sensitivity may be mediated via regulation of lipid metabolism.

- Plasma cholesterol in animal models has been shown to be reduced by mushroom consumption. The hypocholesterolemic effect appears to be due partly to an increased rate of low density lipoprotein (LDL) and high-density lipoprotein (HDL) catabolism. While some studies have postulated eritadenine or angiotensin I – converting enzyme inhibitory peptides as the hypocholesterolemic agents, similar effects on cholesterol, and other biomarkers of cardiovascular risk, and have been demonstrated by consumption of mushroom (e.g. *Agaricus bisporus*) fiber. Such a cholesterol-lowering effect has also recently been reported in humans.

- Extracts from some mushrooms (e.g. *Agaricus blazei* and *A. brassiliensis*) have been reported to have anti-viral properties *in vitro*. The studies carried out to date suggest that the mushroom extracts do not have an effect on reducing viral adsorption and do not show any virucidal effect (i.e they do not kill the virus), but they may act at the initial stage of the replication of a virus.

- Spores of mushrooms are airborne components and can be the cause of hypersensitivity / respiratory allergy. The small number of cases reported, primarily in Japan, usually involve workers in the commercial production of mushrooms, where air-quality may be poor, and hence this condition has been referred to as 'mushroom worker's disease'. The symptoms for this condition usually improve rapidly, either without medication, when the affected person is removed from the factory environment, or after corticosteroid administration via a nasal spray.

- Significant antioxidant activities *in vitro* have been reported in several varieties of mushrooms. The antioxidant activities appear to be related to the polyphenolic content. The antioxidant activity in mushrooms is thermo-stable (to heating over 100ºC for extended periods of time e.g. 30 min) and in some cases increases during heating suggesting that antioxidant activity would be maintained in cooked mushrooms. L-ergothioneine is a biologically active antioxidant in mushrooms and its production in mushrooms can be enhanced by addition of histidine to the growth medium/compost.

Introduction

Mushrooms – the fruiting bodies of macroscopic filamentous fungi that grow above the ground have been a part of the human diet and used as a source of both food and medicine for centuries. Wild mushrooms have been a staple food in some regions and many forms are still prized as delicacies in haute cuisine. Interest in mushrooms as a regular food source in an everyday diet expanded in the 1940s due to wartime shortages of food and has continued to grow as commercial cultivation methods have enabled mushrooms to become a year round secure and reliable food source.

Mushrooms grow in most parts of the world, in various climates and on a variety of substrates from fresh plant residues through to well-composted materials. The fact that each mushroom type grows in a particular and well-defined ecology or habitat has allowed the cultivation of several species whose habitat can be readily and cheaply reproduced on a commercial scale. The use of agricultural and industrial wastes, particularly lignocellulosic materials, for growing substrates make mushroom growing an economical, low-cost form of food production.

Worldwide, around 25-30 species are cultivated or sold commercially, although about 2,000 species are regarded as edible. The white button mushroom (*Agaricus bisporus*), which was cultivated as far back as the early 1700s by Parisians in caves, is the most widely cultivated form in the USA, Europe and parts of Asia. The next most important commercial species are Shiitake (*Lentinus edodes*) straw mushroom (*Volvariella volvacea*), oyster mushroom (*Pleurotus ostreatus*) and winter mushroom (*Flammulina ostreatus*).

Although mushrooms belong to neither the plant nor animal kingdom, in culinary terms, they are regarded as a vegetable, and are considered as such by most nutritional guides. Although the Australian Guide to Healthy Eating explicitly includes mushrooms in its educational brochures, background information states that the vegetable category is primarily defined by its vitamin A (B carotene) composition and secondarily by its content of carbohydrate, fibre, magnesium, iron, vitamin C, folate and potassium. Similarly, the

Canada Food Guide explicitly mentions mushrooms in the vegetable category, as does the US MyPyramid Guide in the "other vegetables" category. The Eatwell Plate of the British Foods Standards Agency includes mushrooms in the fruit/vegetable category and includes mushrooms in the plate illustration. The Chinese Food Pagoda Guide also includes mushrooms in the vegetable category. One half cup of mushrooms is deemed 1 serve/serving of a vegetable.

Alongside the wild mushroom's long history as a food source is an equally long history of beliefs about their curative abilities in all traditional medicine systems – both the folk medicine of the western world and traditional medicine of the orient.

Studies on the consumption of mushrooms have been described in the scientific literature for well over 100 years with one of the earlier reports on edible mushrooms appearing in the prestigious journal *Science* in 1889 (Anon, 1889).

While there is a very large volume of published information on mushrooms and potential effects (positive and negative) on human health, this report aims to critically evaluate the published literature with a view to identifying scientifically-valid research from which important messages can be formulated on the effects of mushroom consumption on human health. The project brief covered *Agaricus bisporus* and 17 culinary specialty and nutraceutical specialty mushrooms, however some additional culinary and nutraceutical mushrooms have also been included where significant information was available on consumption and health.

The scientific literature in this report is categorised both by health condition and subsequently, the information is also grouped by mushroom variety later in the report for readers interested in specific mushroom varieties.

Methodology

Evaluation of Medical, Scientific and Technological Information

The information in *Mushrooms and Health 2008* was sourced via detailed and thorough strategic electronic searches of medical, scientific and technical literature based on the mushroom varieties and health conditions identified in the research proposal. The systematic literature searches were carried out using the following databases:

PubMed – a service of the US National Library of Medicine that includes over 16 million citations from the MEDLINE database and other life science journals.

SCOPUS - an abstract database covering 25 million abstracts from over 14,000 journals across 4,000 publishers.

Web of Science - 5,700 major journals across 164 scientific disciplines.

CSIRO Electronic Journals Collection (4,000 e-journals).

AGRICOLA - includes bibliographic citations for journal articles, monographs, proceedings, theses, patents, translations, audiovisual materials, computer software, and technical reports covering all aspects of primary international information sources in agriculture and related fields. The literature cited is mainly in English, but over one-third of the database comprises citations in Western European, Slavic, Asian, and African languages.

The captured records were cross-checked across the above databases as well as with records from Food Science and Technology Abstracts (FSTA), Cambridge Scientific Abstracts (CSA) and ISI Proceedings. Epidemiological and clinical trials were also included in the review and evaluations. The journals with high impact factors and scientific credibility are indexed in these databases.

Following a detailed search and evaluation of the above databases, approximately 11,000 published papers were downloaded into a fully-searchable electronic (Procite ®) database for analysis. An initial screening/filtering of the data to capture the most relevant published works resulted in approximately 3,000 papers which were evaluated in detail. The searches were completed in March 2008.