Food Chemistry 243 (2018) 373–381

Contents lists available at ScienceDirect

Food Chemistry

journal homepage: www.elsevier.com/locate/foodchem

Review

Anti-inflammatory properties of edible mushrooms: A review

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ARTICLE INFO

Keywords:
Edible mushroom
Basidiomycota
Indole compounds
Phenolic compounds
Bioelements
Anti-inflammatory properties

ABSTRACT

Mushrooms have been used extensively, owing to their nutritional and medicinal value, for thousands of years. Modern research confirms the therapeutic effect of traditionally used species. Inflammation is a natural response of the immune system to damaging factors, e.g. physical, chemical and pathogenic. Deficiencies of antioxidants, vitamins, and microelements, as well as physiological processes, such as aging, can affect the body's ability to resolve inflammation. Mushrooms are rich in anti-inflammatory components, such as polysaccharides, phenolic and indolic compounds, mycosteroids, fatty acids, carotenoids, vitamins, and biometals. Metabolites from mushrooms of the *Basidiomycota* taxon possess antioxidant, anticancer, and most significantly, anti-inflammatory properties. Recent reports indicate that edible mushroom extracts exhibit favourable therapeutic and health-promoting benefits, particularly in relation to diseases associated with inflammation. In all certainty, edible mushrooms can be referred to as a "superfood" and are recommended as a valuable constituent of the daily diet.

1. Introduction

Inflammation is a natural response of the immune system to damage from physical, chemical and pathogenic factors. Acute inflammation is a brief process, which is typically subjected to spontaneous resolution. However, inflammation may transform into a chronic state in certain cases (Dennis & Norris, 2015). Deficiencies of antioxidants, vitamins, anti-inflammatory elements (zinc, selenium), as well as physiological processes, such as the age of a person, may cause inefficient resolution of inflammation. Chronic inflammation characterizes autoimmune diseases and it also accompanies diseases of the cardiovascular system, metabolic and neurodegenerative diseases, and cancers (Okin & Medzhitov, 2012).

Modern medicine benefits from immunological research to gather significant information on the functioning of the immune system. One such field is that of pharmacotherapy involving the use of drugs to resolve chronic inflammation without any side effects. Another key domain of research is linked to that of the immunosuppressive microenvironment of tumor cells (Nathan, 2002; Wang & DuBois, 2015).

Mushrooms have been used for their nutritional and medicinal properties for centuries. They have been a significant therapeutic raw material in folk medicines; for example, *Ganoderma lucidum* (Lingzhi or Reishi mushroom) was considered a panacea in traditional Chinese medicine. Modern research corroborates the therapeutic effect of traditionally used species (Drori et al., 2016).

Edible species constitute a good source of carbohydrates, mainly chitin that fulfills the role of dietary fibre. They are a valuable source of proteins containing essential amino acids, and thus they may be considered an alternative to animal products (Dembitsky, Terent'ev, & Levitsky, 2010). Moreover, mushrooms are low in calories, which is due to their low fat content, yet they are rich in polyunsaturated fatty acids (PUFAs) that are beneficial for health. The dietary and medicinal value of edible mushrooms is further supported by the fact that they are sources of numerous biologically active and health-promoting compounds. Mushrooms contain secondary metabolites which exhibit a range of beneficial properties, such as antioxidative, antibacterial, antiviral, anticancer, and anti-inflammatory properties, as well as the ability to improve the functioning of the cardiovascular system (Kalač, 2010a). The aim of the presented work was to describe the anti-inflammatory properties of edible mushrooms.

2. Polysaccharides

Fungal polysaccharides have been shown to have a positive effect on human health. Trehalose, a disaccharide, constitutes a reserve material and imparts protective properties to cells against protein denaturation. In a study on the model of subarachnoid hemorrhage conducted with the use of RAW264.7 macrophages and human umbilical vein endothelial cells (HUVEC), it was demonstrated that trehalose can inhibit pro-inflammatory proteins, namely, cyclooxygenase-2 and inducible

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http://dx.doi.org/10.1016/j.foodchem.2017.09.149
Received 4 July 2017; Received in revised form 8 September 2017; Accepted 28 September 2017
Available online 30 September 2017
0308-8146/

Table 1
Selected components from fruiting bodies of edible mushrooms and their anti-inflammatory properties.

Substances	Mechanisms of action	Mushroom species (examples)	References
Saccharides: - trehalose, - β-glucans (e.g. lentinan), - chitosans	repression of pro-inflammatory proteins: cyclooxygenase-2, inducible nitric oxide synthase (iNOS) and interleukin-1 (IL-1) inhibition of IκB-α subunit degeneration, inhibition of nuclear transcription factor NF-κB signalling, reduction of lipid peroxidation, prevention of DNA damage and reduction of metabolites with carcinogenic character, anti-mutagenic, chemo- and radioprotective activity, prebiotics, growth stimulation of normal bacterial intestinal flora, anti-lipidemic effect *via* inhibition of: fatty acid synthase, acyl-CoA synthase and fatty acid binding protein 4 (FABP4) and up-regulation of PPARα, inhibition of adipocyte maturation, down-regulation of leptin hormone and sterol regulatory binding element protein (SREBP) signalling, inhibition of the 3-hydroxy-3-methyl-glutaryl-CoA reductase (HMG-CoA) anti-diabetic effect *via* reduction of lipid peroxidation, inhibition of α-glycosidase, up-regulation of insulin – response glucose transporter GLUT-4 immunostimulatory activity, binding to the receptors (TLRs, PRRs, CR3, dectins-1) of immune cells activation of macrophages and NK cells, influence on growing, maturation and proliferation of the immune cells	*A. bisporus,* *L. edodes,* *T. versicolor,* *I. obliquus,* *P. ostreatus,* *G. lucidum*	Belkaid and Hand (2014), Chang et al. (2007), Kozarski et al. (2011), Friedman (2016), Jedinak et al. (2011), Novak and Vetvicka (2009), and Wannet et al. (1998)
Proteins - lectins	inhibitory activity against proliferation of tumor cells without cytotoxicity to the normal cells, immunoregulatory properties, stimulation of Th-1 lymphocytes population through induction of IL-2 and IFN-γ, inhibition of COX-2, prostaglandin E2 synthase (cPGES) and subunits p50 and p65 of NF-κB synthesis,	*L. edodes,* *A. bisporus,* *P. ostreatus,* *T. mongolicum, V. volvacea*	Jedinak et al. (2011), Novaes et al. (2011), Singh et al. (2016) and Wang et al. (1996)
Fatty acids: - oleic acid - palmitic, - linoleic acid, - α-linoleic acid	inhibition of aromatase activity, an enzyme participating in estrogen synthesis, activation of peroxisome proliferator-activated receptor PPARα and PPARϒ	*A. bisporus,* *C. cibarius,* *I. badia*	Ayaz et al. (2011), Chen et al. (2006), Grzywacz et al. (2016) and Hong et al. (2012)
Phenolic compounds: - gallic acid - protcatechuic acid - *p-* hydroxybenzoic acid - *p-* coumaric acid - cinnamic acid - caffeic acid	inhibition of free radical formation, inhibition of cyclooxygenase, lipoxygenases, microsomal monooxygenase, NADH oxygenase, as well as C protein kinase, inhibition of leukocyte adhesive molecules generation, repression of IL-1β and IL-6 protein synthesis	*I. badia,* *A. bisporus,* *B. edulis,* *C. gambosa,* *H. marzuolus,* *L. deliciosus,* *E. granulatus*	Ferreira et al. (2009), Karbownik; Liu et al. (2013); Moon et al.; Muszyńska, Sułkowska-Ziaja, & Ekiert (2013), Palacios et al. (2011), Reiter; Calvo; Reis et al. (2012) and Stanikunaite et al. (2009)
Indole compounds: - melatonin - L-trytptophan - 5-hydroxy-L-tryptophan	inhibition of leukocyte adhesive molecules generation and thus influencing their migration process, regulation of cytokine production, reducing lipid peroxidation, activation and migration of immune cells through TLRs and PRRs receptors protein serotonylation	*C. cibarius,* *A. bisporus,* *I. badia,* *L. deliciosus,* *L. scabrum,* *S. bovinus,* *S. luteus,* *P. ostreatus,* *T. equestre,* *A. mellea*	Kała et al. (2017), Muszyńska, Kała, Firlej, et al. (2016) Muszyńska, Kała, Sułkowska-Ziaja, et al. (2016), Palacios et al. (2011). Reiter et al. (2000)
Vitamins: - vitamins of B group (thiamine,riboflavin, biotin, pyridoxine) - viamine C - tocopherols	prevention of cellular membrane phospholipid peroxidation, antioxidant properties, inhibition of NF-κB signalling, repression of aminotransferases and INF-ϒ, repression of hsCRP protein, free radical scavengers,	*C. cibarius,* *A. bisporus,* *T. microcarpus,* *T. tyleranus,* *T. clypeatus,* *V. speciosa,* *P. tenuiculus*	Barros et al. (2008), Drori et al. (2016), Ferreira et al. (2009), Jiang (2014), Muszyńska, Kała, Firlej, et al. (2016), Muszyńska et al. (2017), Nakalembe et al. (2015) and Stepien et al. (2013)
Terpenoids - carotenoids (β-carotene, lycopene)	inhibition of NF-κB signalling, repression of pro-inflammatory proteins: COX-2, cPGES, iNOS, TNF-α and IL-6	*G. lucidum,* *P. cocos,* *L. perlatum,* *M. procera,* *P.ostreatus*	Ferreira et al. (2009), Iakovidis et al. (2011), Jedinak et al. (2011), Jiang et al. (2008), Jeong et al. (2014), Kalač (2010b) and Yaoita et al. (2014)
Ergothioneine, Glutathione	antioxidant effects, free radical-scavengers, antimutagenic, chemo- and radioprotective activity	*C. comatus,* *A. bisporus,* *B. edulis*	Asahi et al. (2016)
Bioelements - zinc - selenium - - copper	metallothionein synthesis, inhibition of NF-κB signalling, free radical scavengers, antioxidant properties	*A. bisporus,* *C. cibarius,* *I. badia,* *L. perlatum,* *M. procera,* *A. pes-caprae*	Dogan et al. (2016), Falandysz (2008), Grzywacz et al. (2015), Grzywacz et al. (2016), Iakovidis et al. (2011) Kalač (2010b), Muszyńska et al. (2015) and Reczyński et al. (2013)