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# Myco-based Aromatics: Sustainable Frontiers in Bio-flavour and Fragrance Industry

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## ABSTRACT:

Aromatic compounds are characterized by flat, conjugated six-carbon cyclic structures. These are widely used in pharmaceuticals, perfumery, pigments, food, beverage, bio-polymers and other specialty biochemical industries. Conventionally aromatic compounds are derived from either petroleum or from plants, however, their production is linked with restricted workability and environmental side effects. Therefore, there is need to explore new methods for the sustainable production of the commercial aromatic volatile compounds. In this aspect, fungi can play promising role and the fungal metabolic pathways can be triggered for the biosynthesis of bioflavours and fragrances of commercial importance. The present research article overviews the potential role of fungi in flavour and fragrance industry, current global market trends for myco-based flavours and fragrances and their future prospects.

**KEYWORDS:** Bioflavours, myco-based fragrances, shikimic acid pathway, sustainability, fungal metabolic pathway.

## INTRODUCTION:

The global flavour and fragrance industries are undergoing paradigm shift due to recent updates in myco-technology. The traditional methods of flavours and fragrance extractions are dependent on plant-based extraction and chemical synthesis and hence faced great challenges like raw material unavailability, environmental influence, high cost of production and synthesis, transportation difficulties, and so on. This demands the explore of alternative cost effective, eco-friendly, sustainable production technology. The role of fungal fermentation technology has come up with a sustainable solution that enables the production of high-value myco-based ingredients useful in global flavour and fragrance industry. Presently, manufacturers can produce myco-based flavours and fragrances in a sustainable manner in a scalable, consistent quantity by influencing the industrial bioprocessing and fermentation technology. The fungal capability of mimicking the natural metabolic pathways and innovations in controlled fermentation technology make them better in producing complex flavours and aromas. This research article throws light on the potential role and commercial applications of fungi in flavour and fragrance industry, global market trends for myco-based flavours and fragrances and their future prospects.

## COMMERCIAL ROLE AND APPLICATIONS OF FUNGI IN FLAVOUR AND FRAGRANCE INDUSTRY:

Fungi have been reported to play vital role in fermentation industry for centuries. The recent advancements in fungal biotechnology have shown that these fungi can be genetically engineered and biochemically optimized to produce desired flavours and fragrances in a sustainable manner.

*Saccharomyces cerevisiae* synthesise esters, lactones, and volatile sulphur molecules possessing fruity and creamy flavours (Vancouver, 2025). *Kluyveromyces lactis* produce de novo fruity, floral flavour-terpenes such as citronellol, linalool and geraniol (Vandamme, 2003). Many filamentous fungi can naturally break down lignin and metabolize lignin-derived aromatic compounds. Lignin is the second most abundant plant biomass on earth and comprises various aromatic molecules. A few recent studies have focused on conversion of lignin derived, aromatic compounds into vanillic acid, methoxyhydroquinone or protocatechuic acid by *Aspergillus niger* (Lubbers, et.al., 2021). Filamentous fungal genera like *Aspergillus, Penicillium,* and *Trichoderma* carry out biosynthesis of vanillin, benzaldehyde, and cinnamaldehyde which are largely used in food, beverage, cosmetic, perfumery and in pharmaceutical industries (Vancouver, 2025, Converti, *et.al.,* 2010, Krings *et.al.,* 2001). Vanillin has been produced from ferulic acid in *Aspergillus luchuensis* (Taira, *et.al.,* 2018). Similarly, in *Myceliophthora thermophila*, the decarboxylation of ferulic acid to *p*-vinylguaiacol resulted in the synthesis of vanillic acid. The conversion of ferulic acid into vanillic acid has also been observed in a range of ascomycota, namely in *A. niger* and *Botrytis*, *Cephalosporium*, *Penicillium*, *Trichoderma*, and *Verticillium* spp. (Lubbers, *et.al.,* 2019) *Ceratocystis* sp. are famous for their terpenes production possessing floral odours (Vandamme, 2003). *Trichoderma viride, Trichoderma harzianum* and *Trichoderma gamsii* produce 6-pentyl-α-pyrone (6-PP) having coconut flavour (Bleumke and Schrader, 2001; Palomares et al., 2001, De Souza, et.al., 2008). *Williopsis saturnus* var. *mrakii* synthesizes important levels of volatile branched acetates, especially 3-methylbutyl-acetate, possessing aroma of banana. The soy sauce yeast *Zygosaccharomyces Rouxii* and *Aspergillus* sp. produce unique compound like Furaneol, 2,5-dimethyl-4-hydroxy-3(2H)-furanone (DMHF) exhibiting strawberry flavour in dilute concentrations and caramel flavour in high concentrates (Dahlen *et al.*, 2001). Methylketones (2-alkanones) produced by *Penicillium Roquefortii* and *Penicillium Camembertii* by processing medium length fatty acids give unique cheesy flavour and aroma to Roquefort, Camembert and Stilton cheese (Vandamme, 2003). *Botryodiplodia theobromae,* a plant fungal pathogen, coverts α-linolenic acid into methyl-7-iso-jasmonic acid, possessing sweet floral, jasmine-like fragnance. *Saccharomyces cerevisiae, Kluyveromyces marxianus* convert L-phenylalanine into 2-phenylethanol possessing rosy fragrance (Lomascolo et al., 2001) *Lasiodiplodia theobromae, Fusarium solani, Aspergillus* sp., *Penicillium* sp., and *Chaetomium* sp. play significant role in fragrant resinous heartwood production by Agarwood tree (*Aquilaria malaccensis*) (Sangareswari, 2016). *Torulopsis bombicola* convert palmitic acid into ω-hydroxypalmitic acid ester, which can then be cyclised into hexadecanolide lactone possessing musk like aroma (Cheetham, 1993). Fungi produce specific lactones and methylketones attributing mushroom flavours and grassy green fragrances using fatty acids, added as precursors (Feron *et al.,* 1996). Fungi like *Botryosphaeria dothidea* and *Botryodiplodia theobromae* can convert valencene, a sesquiterpene hydrocarbon found in oranges, into nootkatone giving grapefruit like aroma (Furusawa, 2005). *Nidula niveo-tomentosa* has been exploited industrially for the biosynthesis of raspberry ketone (Yi Zhang, *et.al.,* 2024, Fischer, et.al., 2001). Yi Zhang, *et.al.,* also demonstrated that the UV radiation stimulate raspberry ketone production in fungal cultures (2024). Research has shown that the fungi living on flowers can significantly impact their scent, influencing the quantity and composition of their perfumes (Peñuelas, *et.al.,* 2014). A yellowish-brown liquid obtained from mushrooms is used in preparation of alcoholic perfumes, anti-perspirants, and creams. Some mushrooms are famous for their pleasant, anise-like, fruit-like, or cucumber notes, while others can have more pungent odours like garlic or even faecal matter (Moliszewska, 2014). Such mushrooms are of great importance in commercial food and perfume industry due to their distinct flavours and unique fragrances. Eugenol, a highly biologically active compound found in essential plant oils was reported to be converted into *p*-vinylguaiacol by *S. commune*, *P. variotii* and *Fusarium solani* (Mohammed, *et.al.,* 1989, Nazareth, *et.al.,*1986, Ghosh, *et.al.,* 2005). *p*-vinylguaiacol is a volatile phenolic compound known for its tobacco flavour, a molecule that is used both as a flavour and as a pharmaceutical intermediate (Sun, *et.al.,* 2018). Notably, several recent studies have focused on developing aromatic compounds from agro-industrial residues. The production of gallic acid from tannic acid by *A. niger* and *Aspergillus oryzae* was demonstrated in solid-state fermentation of soybean hull and grape pomace (Cabezudo, *et.al.,* 2023).

Fungal enzymes play catalysing role in biosynthesis of myco-based aromas and flavours. The myco-enzymes break down complex substrates into volatile aromatic compounds and thereby enhance their sensory values useful in food, beverages, and perfume industries. Fungal lipases and esterase synthesise fruity esters used in dairy, wine, and fruit-based industries (Chandra, *et.al,* 2020). Laccases and peroxidases of fungal oxidise the lignin-derived precursors into vanillin and related compounds useful in enhancing the creamy vanilla tastes of bakery goods, candies, ice-creams and beverages (Aza, *et.al.,* 2023). These compounds are equally in demand in cosmetic and pharmaceutical industries owing to their pleasantly refreshing aroma. On fermentation, the fungal glycosidases and proteases process the precursor molecules into the aromatic compounds responsible for enhancing the flavours of coffee, cocoa, and cheese (Vancouver, 2025).

Shikimic acid pathway is one of the primary route for the biosynthesis of volatile aromatic compounds by fungi. The fungi synthesise volatile aromatic compounds such as aromatic amino acids, viz., phenylalanine, tyrosine, and tryptophan which act as the essential building blocks for proteins in fungi and also function as precursors for the production of various commercial secondary metabolites possessing flavours and aromas. The shikimate pathway uses five enzymes, viz., 3 – dehydroquinate dehydratase, shikimate dehydrogenase, shikimate kinase, EPSP synthase, and chorismate synthase. In fungi, the pathway starts with two substrates, phosphoenol pyruvate and erythrose – 4 – phosphate, which are processed by DAHP synthase and 3-dehydroquinate synthase to form 3-dehydroquinate. The pathway ends with chorismate (chrorismic acid), a substrate for the three aromatic amino acids (Francenia Santos-Sánchez, *et.al.,* 2019). *Trichoderma ovalisporum* (Dang, *et.al.,* 2010), *Penicillium griseofulvum* (Simonart, *et.al.,* 1960) and *Fusarium decemcellulare* (Qader, *et.al.,* 2018) have been reported to produce shikimic acid. The accumulation of shikimic acid in the oyster mushroom (*Pleurotus ostreatus*) was reported to increase upon blue light stimulation, leading to increased amounts of rate-determining enzymes that resulted in increased amounts of shikimate pathway entry compounds (Kojima, et.al., 2015).

**GLOBAL MARKET SCENARIO FOR BIOFLAVOURS AND FRAGRANCES:**

The worldwide demand for bioflavours and fragrances is growing enormously due to the consumers' awareness about side effects of aromatic compounds of synthetic origin. The global market for microbial flavours and fragrances is subjected to grow at a compound annual growth rate of 7.8% between 2023 and 2032 due to increased preference for natural flavours and fragrances in food, beverage, cosmetic, and pharmaceutical industries. The global aromatics manufacturing market size value was 233.6 billion US$ in 2021 and has been anticipated to reach 382.4 billion US$ by 2030 (Materials and Chemicals - Aromatics Market, 2022). Furthermore, CRISPR-based genome editing has enabled the precise activation or suppression of desired genes in fungi responsible for the production of aromatic compounds. Recombinant expression of plant-derived biosynthetic pathways has allowed fungi to generate unique flavours which are difficult to extract from plants. As global industries transition towards sustainable production of aromas and flavours, the exploration of fungi would become inevitable.

**FUTURE PROSPECTS:**

Unlike plant-based sources, fungal fermentation is independent of seasonal fluctuations, climate change impact and supply chain commotion. By reducing the land and water use, they minimize the carbon emissions and provide environment-friendly alternative. The target aromatic fungal compounds can be synthesised in a short span as it is free from laborious, time consuming field based cultivations. The screening of filamentous fungi for production of aromatic compounds has yet to be thoroughly appraised and hence there lies a great potential and future prospects.

**CONCLUSION:**

Fungi possess large metabolic capabilities which need to be tapped for the production of wide range of flavours and aromatic compounds. Use of fungi further reduces the dependency on season-based availability of aromatic plants and their extractions. Fungal efficiency can be scaled up through fermentation in controlled conditions to ensure the continuous supply of quality products. Thus, it can be concluded that the fungi are unique, versatile organisms providing the eco-friendly platform for the sustainable production of bio-flavours and fragrances and thereby offer great prospects for food, beverage, confectionary, cosmetics and pharmaceutical industries pursuing sustainable production alternatives.

**CONFLICTS OF INTEREST:** The author declares no conflicts of interest.

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**REFERENCES:**

1. Aza, P., & Camarero, S. (2023). Fungal Laccases: Fundamentals, Engineering and Classification Update. *Biomolecules*, *13* (12), 1716. https://doi.org/10.3390/biom13121716

2. Bleumke, W. and Schrader, J. (2001). Integrated bioprocess for enhanced production of natural flavors and fragrances by Ceratocystis moniliformis. Biomolecular Engineering 17: 137-142.
3. Cabezudo I, Galetto CS, Romanini D, Furlán RLE, Meini MR. (2023). Production of gallic acid and relevant enzymes by *Aspergillus niger* and *Aspergillus oryzae* in solid-state fermentation of soybean hull and grape pomace. Biomass Convers Biorefin. 13(16):14939 – 14947. https://doi.org/10.1007/s13399-022-03435-8
4. Chandra, P., Enespa, Singh, R. *et al.* (2020). Microbial lipases and their industrial applications: a comprehensive review. *Microb Cell Fact* 19, 169. https://doi.org/10.1186/s12934-020-01428-8
5. Cheetham, P.S.J. (1993). The use of biotransformation for the production of flavours and fragrances. Trends in Biotechnology 11: 478-488.
6. Converti A, Aliakbarian B, Domínguez JM, Bustos G, Vázquez, Perego P. Microbial production of biovanillin. Brazilian J Microbiol. (2010); 41: 519–30. https://doi.org/10.1590/S1517-83822010000300001.
7. Dahlen, T., Hauck, T., Wein, M. and Schwab, W. (2001). 2,5-dimethyl-4-hydroxy-3(2H)-furanone as a secondary metabolite from D-fructose-1,6-diphosphate metabolism by Zygosacharomyces rouxii. Journal of Bioscience and Bioengineering 91: 352-358.
8. Dang L, Li G, Yang Z, Luo S, Zheng X, Zhang K. (2010). Chemical constituents from the endophytic fungus *Trichoderma ovalisporum* isolated from *Panax notoginseng*, Ann Microbiol. 60(2):317–320. https://doi.org/10.1007/s13213-010-0043-2.
9. Dang L, Li G, Yang Z, Luo S, Zheng X, Zhang K. (2010). Chemical constituents from the endophytic fungus *Trichoderma ovalisporum* isolated from *Panax notoginseng*, Ann Microbiol. (2):317–320. https://doi.org/10.1007/s13213-010-0043-2.
10. De Souza Ramos, A., Fiaux, S. B., & Leite, S. G. (2008). Production of 6-pentyl-α-pyrone by trichoderma harzianum in solid-state fermentation. *Brazilian journal of microbiology: [publication of the Brazilian Society for Microbiology]*, *39*(4), 712–717. https://doi.org/10.1590/S1517-838220080004000022
11. Feron, G., Bonnarme, P. and Durand, A. (1996). Prospects in the microbial production of food flavours. Trends in Food Science and Technology 7: 285-293.
12. Fischer, M., Böker, A., & Berger, R. G. (2001). Fungal formation of raspberry ketone differs from the pathway in plant cell culture. *Food Biotechnology*, *15*(3), 147–155. https://doi.org/10.1081/FBT-100107626
13. Francenia Santos-Sánchez, N., Salas-Coronado, R., Hernández-Carlos, B., & Villanueva-Cañongo, C. (2019). Shikimic Acid Pathway in Biosynthesis of Phenolic Compounds. IntechOpen. https://doi.org/10.5772/intechopen.83815
14. Furusawa, M., Hashimoto, T., Noma, Y., & Asakawa, Y. (2005). Highly efficient production of nootkatone, the grapefruit aroma from valencene, by biotransformation. *Chemical & pharmaceutical bulletin*, *53* (11), 1513–1514. https://doi.org/10.1248/cpb.53.1513
15. Ghosh S, Sachan A, Mitra A. (2005). Degradation of ferulic acid by a white rot fungus *Schizophyllum commune*. World J Microbiol Biotechnol. 21(3): 385–8. https://doi.org/10.1007/s11274-004-3621-2.

16. Kojima M, Kimura N, Miura R. (2015). Regulation of primary metabolic pathways in oyster mushroom mycelia induced by blue light stimulation: accumulation of shikimic acid. Sci Rep. 5(1):8630. https://doi.org/10.1038/srep08630.
17. Kojima M, Kimura N, Miura R. (2015). Regulation of primary metabolic pathways in oyster mushroom mycelia induced by blue light stimulation: accumulation of shikimic acid. Sci Rep. 5(1):8630. https://doi.org/10.1038/srep08630
18. Krings U, Pilawa S, Theobald C, Berger RG. (2001). Phenyl propenoic side chain degradation of ferulic acid by *Pycnoporus cinnabarinus* - elucidation of metabolic pathways using [5-2H]-ferulic acid. J Biotechnol. 85(3): 305–14. https://doi.org/10.1016/S0168-1656(00)00396-5.
19. Lee J, Wendisch VF. (2017). Biotechnological production of aromatic compounds of the extended shikimate pathway from renewable biomass. J Biotechnol. 257: 211–21. https://doi.org/10.1016/j.jbiotec.2016.11.016.
20. Lim, J. S., Hong, J. H., Lee, D. Y., Li, X., Lee, D. E., Choi, J. U., Lee, K. Y., Kim, K. H., & Cho, Y. C. (2023). 6-Pentyl-α-Pyrone from *Trichoderma gamsii* Exert Antioxidant and Anti-Inflammatory Properties in Lipopolysaccharide-Stimulated Mouse Macrophages. *Antioxidants (Basel, Switzerland)*, *12*(12), 2028. https://doi.org/10.3390/antiox12122028
21. Lomascolo, A., Lesage-Meesen, L., Haon, M., Navarro, D., Antona, C., Faulds, C. and Marcel, A. (2001). Evaluation of the potential of Aspergillus niger species for the bioconversion of L-phenylalanine into 2-phenylethanol. World Journal of Microbiolial Biotechnology 17: 99-102.
22. Lubbers RJM, Dilokpimol A, Nousiainen PA, Cioc RC, Visser J, Bruijnincx PC, et al. (2021). Vanillic acid and methoxyhydroquinone production from guaiacyl units and related aromatic compounds using *Aspergillus niger* cell factories. Microb Cell Fact. 20(1):151. https://doi.org/10.1186/s12934-021-01643-x
23. Lubbers RJM, Dilokpimol A, Nousiainen PA, Cioc RC, Visser J, Bruijnincx PC, et al. (2021). Vanillic acid and methoxyhydroquinone production from guaiacyl units and related aromatic compounds using *Aspergillus niger* cell factories. Microb Cell Fact. 20(1):151. https://doi.org/10.1186/s12934-021-01643-x.
24. Lubbers RJM, Dilokpimol A, Visser J, Mäkelä MR, Hildén KS, De Vries RP. (2019). A comparison between the homocyclic aromatic metabolic pathways from plant-derived compounds by bacteria and fungi. Biotechnol Adv. 37(7): 107396. https://doi.org/10.1016/j.biotechadv.2019.05.002.
25. Materials and Chemicals - Aromatics Market. (2022). https://www.reportsanddata.com/report-detail/aromatics-market.
26. Mir R, Jallu S, Singh TP. (2015). The shikimate pathway: review of amino acid sequence, function and three-dimensional structures of the enzymes. Crit Rev Microbiol. 41(2):172–89. https://doi.org/10.3109/1040841X.2013.813901.
27. Mohammed R, Françoise S-M, Régine S, Karl-Erik E. (1989). Metabolism of ferulic acid by *Paecilomyces variotii* and *Pestalotia palmarum*. Appl Environ Microbiol. 55(9):2391–8. https://doi.org/10.1128/aem.55.9.2391-2398.1989.
28. Moliszewska, Ewa. (2014). Mushroom flavour. Folia Biologica et Oecologica. https://doi.org/10. 10.2478/fobio-2014-0007.

29. Nazareth S, Mavinkurve S. (1986). Degradation of ferulic acid via 4-vinylguaiacol by *Fusarium solani* (Mart.) Sacc., Can J Microbiol. 32(6): 494–97. https://doi.org/10.1139/m86-090.
30. Palomares, M.R., Negrete, A., Miranda, L., Flores, C., Galindo, E. and Serrano-Carreon, L, (2001). The potential application of aqueous two-phase systems for in situ recovery of 6-pentyl-α-pyrone produced by Trichoderma harzianum. Enzyme Microbial Technology 28: 625-631.
31. Peñuelas J, Farré-Armengol G, Llusia J, Gargallo-Garriga A, Rico L, Sardans J, Terradas J, Filella I. (2014) Removal of floral microbiota reduces floral terpene emissions. Sci Rep. 22(4):6727http://doi/10.1038/srep06727
32. Qader MM, Kumar NS, Jayasinghe L, Fujimoto Y. (2018). Shikimic acid production by *Fusarium decemcellulare*, an endophytic fungus isolated from *Flacourtia inermis* fruits. J Biologically Act Prod Nat. 8(1): 43–50. https://doi.org/10.1080/22311866.2018.1426494.
33. Sangareswari@Nagajothi, M., Thangamuthu Parthiban, K., Umesh Kanna, S., Karthiba, L. and Saravanakumar, D. (2016) Fungal Microbes Associated with Agarwood Formation. *American Journal of Plant Sciences*, **7**, 1445-1452. https://doi.org/10.4236/ajps.2016.710138
34. Simonart P, Wiaux A. (1960). Production of shikimic acid by *Penicillium griseofulvum* Dierckx. Nature. 186(4718): 78–9. https://doi.org/10.1038/186078a0.
35. Sun LH, Lv SW, Yu F, Li SN, He LY. (2018). Biosynthesis of 4-vinylguaiacol from crude ferulic acid by *Bacillus licheniformis* DLF-17056. J Biotechnol. 2018; 281:144–9. https://doi.org/10.1016/j.jbiotec.2018.07.021.
36. Taira J, Toyoshima R, Ameku N, Iguchi A, Tamaki Y. (2018). Vanillin production by biotransformation of phenolic compounds in fungus, *Aspergillus luchuensis*. AMB Express. 8:1–8. https://doi.org/10.1186/s13568-018-0569-4.
37. Umashankar, P., Nygård, Y. (2024). Filamentous fungi as emerging cell factories for the production of aromatic compounds. *Fungal Biol Biotechnol* 11, 19 https://doi.org/10.1186/s40694-024-00188-z
38. Vancouver, B.C. (2025) The Role of Fungi and Yeast in Flavor, Ingredient, and Fragrance Development: A Techno-Commercial Perspective. FermenteQ. https://www.linkedin.com/pulse/role-fungi-yeast-flavor-ingredient-fragrance-development-techno-commercial-kupic
39. Vandamme, E.J. (2003). Bioflavours and fragrances via fungi and their enzymes. Fungal Diversity 13: 153-166.
40. Yang J, Li FZ, Arnold FH. (2024). Opportunities and challenges for machine learning-assisted enzyme engineering. ACS Cent Sci. 10(2): 226–4. https://doi.org/10.1021/acscentsci.3c01275
41. Yi Zhang, Kheng-Lim Goh, Vladimir Zivkovic, Yuen Ling Ng, Yvonne Chow (2024) Bioproduction of high-value raspberry ketone by submerged fermentation of *Nidula niveo-tomentosa*, Process Biochemistry, 144, 168-178. ISSN 1359-5113. https://doi.org/10.1016/j.procbio.2024.05.029