CHAPTER 37

MUSHROOMS AS A SOURCE OF NATURAL FLAVOR AND AROMA COMPOUNDS

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1. INTRODUCTION

Flavors, aromas, and fragrances are extremely important in the food, cosmetic, and pharmaceutical industries. A flavor is a volatile compound in a foodstuff, whose aromatic properties are detected by the nose. It may be inherently present or produced during processing by chemical reactions or microbial action. Some flavors such as peach, anise-licorice, and almond are due to a single impact flavor compound, 4-decalactone, anisaldehyde, and benzaldehyde, respectively. Others, like mushroom flavor or fruity flavor, are due to a mixture. Flavor compounds are usually present in very low concentrations. Flavor assessment is somewhat subjective; organoleptic evaluation is routinely performed along with chemical analysis. The term fragrance is usually reserved for volatile compounds with applications in the perfume and cosmetic industries.

2. SOURCES OF NATURAL FLAVOR COMPOUNDS

In the past, the only natural sources of flavors and essential oils were derived from plants. While production of flavor compounds from the distillation of plant material does have the advantage of using renewable resources, the products themselves may vary in quality and consistency. Active components often occur in minor quantities or in bound form or only in exotic plants, making isolation difficult and the products expensive. These limitations, combined with the fact that plant growth is subject to seasonal, climatic, and geographical variations and diseases, have resulted in an almost total shift to chemical synthesis for production of flavor and fragrance compounds. Nonetheless, chemical synthesis of compounds also has drawbacks, including the formation of undesirable racemic mixtures (isomers) and the growing aversion of consumers to chemical additives in food, cosmetics, and other household products (16, 30).

While fungi have long been utilized in the food industry, their potential for the industrial production of natural flavor compounds has been overlooked. Many fungi are capable of *de novo* synthesis of flavoring compounds when grown on standard culture media. In fact, sensory properties,

such as sweet, fruity, musty, earthy, and antiseptic, have long been used as taxonomic markers for classification (3). With advances in analytical techniques, it has become evident that the chemical structures of many volatile fungal metabolites are similar to those of well-known fragrance chemicals.

Odor-producing fungi occur in each of the classes (with the possible exception of the Myxomycetes), but the largest number is found within the Basidiomycetes, particularly the fruiting stages commonly referred to as mushrooms. This is not surprising, since Basidiomycetes have enzyme systems capable of catabolizing aromatic substrates. The Ascomycetes and Fungi Imperfecti also contain a large number of aroma-producing organisms. The Phycomycetes have not received much attention.

When a characteristic odor is absent from a mushroom, it may be because the specimen is immature, over-mature and/or incomplete. Many mushroom species, whose natural fruit bodies have no detectable odor, will produce a distinctive scent from the mycelium on agar (3) or in liquid culture (10). Edible and wood-decaying mushrooms and their respective aromatic notes are listed in Table 1.

TABLE 1. Mushrooms and their aromas.

Mushromms	Aromas	References
Agaricus bisporus	strong mushroom	20, 21, 25, 26
Antrodia malicola	faintly fragrant	3, 18, 30
Antrodia xantha	limonene, lemon	3, 18, 30
Armillaria lutea	honey, caramel, whey, meal, fatty, mushroom, blue cheese	10
Armillaria mellea	anise, licorice, fruity grapefruit,	10
Armillaria ostoyae	fruity, quince, fresh, leek, citrus, floral burnt, mushroom	10
*Auriporia aurea*s	weet	15
Boletus edulis	dried mushroom	26
Cantharellus cibarius	mushroom	26
Ceriporiopsis subvermispora	berry, fruity, pineapple, carrot, cheese, burnt caramel, fresh, apple, medicinal, floral, citrus, strawberry	10
Chondrostereum purpureum	moderately fragrant	3, 18,
*Coprinus micaceus*strong	mushroom	3, 18, 30
Cystostereum murrayi	vanilla	3, 18, 30
Daedalea quercina	apples	3, 18, 30
Datronia scutellata	hydrocyanic acid, cherry laure	l3, 18, 30
Dichomitus squalens	almond, bitter almond, fruity	10

TABLE 1 continued.

Mushromms	Aromas	References
Dichostereum effuscata	vegetable soup, boiled carrot, floral	10
Fibroporia vaillantii	faint mushroom	3, 18, 30
Fomes fomentarius	oily, tallow	3, 18
Fomes fraxineus	faint sardine	3, 18, 30
Fomitopsis officinalis	faintly fragrant	3, 18, 30
Fomitopsis pinicola	fish, tallow	3, 18, 30
Ganoderma applanatum	faint tallow	3, 18
Ganoderma oregonense	faintly fragrant	3, 18, 30
Gloeophyllum odoratum	pleasant, fruity, honey, rose, anise, sweet	3, 7, 13, 15, 18, 19, 30
Gloeophyllum sepiarium	slightly spicy	3, 18, 30
Gloeophyllum striatum	iodine, bitter	3, 18
Gloeophyllum trabeum	iodine, bitter, balsamic terpenic, lemon, fruity, resin, wax polish, apple, floral, rose, citrus, mango, peach	10, 18
Grifola frondosa	hydrocyanic acid, cherry laurel nut oil then blue cheese, herbaceous, whey, musty, wild hyacinth, cereals, hyacinth, yeast, cereals then citrus	3, 10, 18, 30
Gyromitra esculenta	mushroom	26
Hapalopilus croceus	narcissus	3, 18, 30
Hapalopilus rutilans	slightly fragrant	3, 18, 30
Haploporus cytisinus	faint sardine	3, 18, 30
Hebeloma sacchariolens	sweet, fragrant, aromatic, fruity orange blossoms	34
Heterobasidion annosum	mushroom, fruity, floral, pungent, peppery, hay, celery	10
Hirschioporus pergamenus	leek, boiled carrot, orange, honey, fruity, sweet, burnt	10
Inocybe corydalina	fruity, jasmine, rose	15, 19, 30, 31
Inocybe pyriodora	fruity, jasmine, rose	15, 31
Inocybe odorata	fruity, jasmine, rose	15, 31
Ischnoderma resinosum	benzaldehyde, anisaldehyde	3, 18, 30
Kuehneromyces mutabilis	earthy then fragrant	3, 18

TABLE 1 continued.

Mushromms	Aromas	References
Lactarius rufus	mushroom	26
Lactarius torminosus	mushroom	26
Lactarius trivialis	mushroom	26
Lentinellus cochleatus	anisaldehyde	3, 15, 18, 30
Lentinula edodes	mushroom, floral, almond, fruity, apple	10
Lentinus lepideus	anisaldehyde, fruity, aromatic, cedar-wood	3, 18, 30
Lenzites betulina	fish, tallow, bitter cocoa, coffee grounds, fruity, bitter almond, camphorated, minty, walnut	3, 10, 18, 30
Lenzites flaccida	tallow	3, 18
Lenzites tricolor	slightly pepper	3, 18, 30
*Lepista irina*iris	oil, orange blossom	2
Lyophyllum ulmarium	slightly fragrant	3, 18, 30
Marasmium alliaceus	garlic	3, 18, 30
Merulius confluens	moderately fragrant	3, 18, 30
Merulius himantioides	iodine, bitter	3, 18
Merulius rufus	faint mushroom	18, 30
Merulius tremellosus	burnt toffee	3, 18, 30
Mycoacia uda	almond, floral, sweet, fruity, faint grassy, hyacinth, gardenia, alcoholic	14, 18, 19, 30
Nigroporus durus	alcoholic, sweet, fruity, fruity-flowery, estery, fragrant, coconut, peach, quince	3, 30
Ossicaulis lignatilis	new meal	3, 18, 30
Paxillus atrotomentosus	unbleached calico	3, 18, 30
Paxillus panuoides	unbleached calico, slightly fragrant	3, 18, 30
Perenniporia subacida	grapefruit, resin, fruity, floral, bitter almond, fermented, soup, cereal, sour, burnt, almond, orange, fruity apple	10
Phaeolus schweinitzii	pleasant, anise	3, 18, 30
Phellinus contiguus	pineapple, menthol, floral, fruity, citrus	10
Phellinus igniarius	faint, pleasant, fruity, floral, sweet fruity, wintergreen, rose	8, 18, 19
Phellinus laevigatus	faint, pleasant, fruity, wintergreen, rose	8, 18, 19

TABLE 1 continued.

Mushromms	Aromas	References
Phellinus pini	fruity, cereals, bitter cocoa, vegetable soup	10
Phellinus robustus	fruity, painting, floral, earthy	10
Phellinus tremulae	faint, pleasant, fruity, floral, sweet, wintergreen, rose	8, 18, 19
Phlebia radiata	butanol, harsh, herbaceous, orange, waxy, sweet, mirabelle, floral, cheese, pungent, fruity, citrus, cauliflower, mushroom, fatty, pineapple, roasted, faded rose, dandelion, burnt wood, musty, peach, creamy, fatty, lavender, almond, heavy, warm, roasted meal	12
Pholiota adiposa	earthy	3, 18, 30
Pholiota lucifera	earthy	3, 18, 30
Pholiota spectabilis	sickly sweet	3, 18
Pholiota squarrosa	strong, earthy	3, 18, 30
Piptoporus betulinus	apples, cereals, pineapple, fruity, coffee, pungent	3, 10, 18, 30
Pleurotus euosmus	fragrant, sweet, floral	3, 18, 30
Pleurotus ostreatus	slightly fragrant, mushroom, fruity, bitter cocoa, anise, almond, yeast	3, 10, 18, 30
Pleurotus sapidus	fragrant	3, 18, 30
Polyporus adustus	slightly fragrant (terpenoid)	3, 18, 30
Polyporus badius	slightly fragrant, resinoid1	8, 30
Polyporus obducens	hydrocyanic acid, cherry laure	13, 18, 30
Polyporus obtusus	moderately fragrant, jasmine	3, 18, 30
Serpula lacrymans	very slight fungus odor	3, 18
Stereum gausapatum	faintly fragrant	3, 18
Stereum hirsutum	faintly fragrant	3, 18, 30
Stereum ostrea	faintly sweet	3, 18
Stereum rugosum	fruity, banana	3, 18, 30
Stereum sanguinolentum	fragrant	3, 18, 30
Trametes rubescens	faint tallow	3, 18
Trametes suaveolens	strong, anise, almond	3, 18, 19, 30

TABLE 1 continued.

Mushromms	Aromas	References
Trametes versicolor	fish, tallow	3, 18, 30
Tricholoma matsutake	mushroom	19
Tyromyces sambuceus	peach, passion fruit	15
Xylobolus frustulatus	fruity, rotting apples, spicy	3, 18, 30
Xylobolus illudens	sweet, banana	3, 18, 30

3. TYPES OF AROMATIC COMPOUNDS

Aromatic compounds are usually classified into two groups: pleasant and unpleasant. Pleasant aromatic compounds include balsamic, almond-, or anise-like odors, and floral or fruity odors suggesting pineapple, honey, lemon, or orange; unpleasant include sulfurous, rubbery, oily, alliaceous, ammoniacal, and putrid (11).

The most important components responsible for the characteristic odors or flavors of essential oils are terpenes. They are hydrocarbons built from a basic isoprene unit with structures that may be open chain, closed chain, cyclic, saturated, or unsaturated. Odor descriptions associated with monoterpenes include rose-like (geraniol), sweet (linalool), and sweet, rose-like (nerol). Sesquiterpenoids, which are generally oxygenated, possess intensely balsamic, citrus or floral odors.

Esters are important aroma compounds of fruits, in which they are present in fairly low concentrations. Fruity flavors are attributed to ester formation caused by the reaction of organic acids with ethanol. Produced as the first synthetic flavors a century ago, esters can also be synthesized by fungi.

Lactones, widely used by the flavoring industry, are characterized a pleasant odor and flavor. They can be formed naturally in foods through a variety of chemical reactions or through biological processes and are described as fruity, coconut-like, buttery, sweet, or nut-like. Although chemical synthesis remains the most practical method of production at this time, optically active lactones in a relatively pure form can be naturally synthesized in fewer steps by fungi.

Pyrazines are the typical aroma components of heated foodstuffs, to which they give a characteristic roasted or nutty flavor. Normally, these heterocyclic, nitrogen-containing compounds are formed through nonenzymatic browning, whereby a carbonyl group and an amine group condense when heated above 100°C. Pyrazines have been isolated from vegetables, and associated sensory properties include bell pepper, peas, potatoes, vegetable, nutty, popcorn, pineapple, grassy, pungent, and earthy.

The same volatile metabolites that contribute to the flavor in some foods, such as edible mushrooms, can also be responsible for off-flavors in others, such as bread, cereals, and dairy products (17). Oxidation of terpenes also causes the formation of off-flavors. Table 2 lists aromatic compounds detected in mushrooms and their characteristic odors.

TABLE 2. Aromatic compounds produced by mushrooms and their characteristic odors.

Compounds	Odors	References
Alcohols		
methanol	alcoholic	18
ethanol	alcoholic	18
propanol	alcoholic	18
1-butanol	butanol	10, 12
1-pentanol	rubbery, harsh, alcoholic	10, 12, 18
1-hexanol	sweet, slightly fruity	4, 9, 10, 12
1-heptanol	herbaceous	10, 12
1-octanol	fruity-flowery, sweet soap, orange, waxy, sweet	4, 9, 10, 12, 27
1-nonanol	sweet, floral, soap	27
1-decanol	sweet, mirabelle	12
1-dodecanol	floral	12
isopropanol	alcoholic	18
isobutanol	alcoholic	18
isopentanol	alcoholic	18
2-methyl-1-propanol	alcoholic, butanol, harsh	4, 9, 10, 12
2-methyl-1-butanol	pungent	10, 12
3-methyl-1-butanol	alcoholic, cheese, pungent	4, 9, 10, 12
2,2-dimethyl-1-hexanol	herbaceous, pungent	10
3-octanol	fruity, cod liver oil, citrus, weakly nutty, fungal	4, 9, 12, 19, 27
4-nonanol	heated plastic	10
3-methyl thiopropanol	sulfuraceous, pungent	10, 12
1-octen-3-ol	mushroom, butter, resinous	9, 10, 12, 19, 20, 21, 26, 27, 28
2-octen-1-ol	fruity	12
trans-2-octen 1-ol	medicinal, oily	27
cis-2-octen-1-ol	oily, musty	19
5-octen-3-ol	floral	12
7-octen-4-ol	cauliflower	10, 12

TABLE 2 continued.

Compounds	Odors	References
2,2-dimethyl-1-hexanol	herbaceous, pungent	10
3-octanol	fruity, cod liver oil, citrus, weakly nutty, fungal	4, 9, 12, 19, 27
4-nonanol	heated plastic	10
3-methyl thiopropanol	sulfuraceous, pungent	10, 12
1-octen-3-ol	mushroom, butter, resinous	9, 10, 12, 19, 20, 21, 26, 27, 28
2-octen-1-ol	fruity	12
trans-2-octen 1-ol	medicinal, oily	27
cis-2-octen-1-ol	oily, musty	19
5-octen-3-ol	floral	12
7-octen-4-ol	cauliflower	10, 12
2-decen-1-ol	floral	12
2,3-butanediol	fatty	10, 12
1,2-heptanediol	herbaceous, bay	10
1,9-nonanediol	pineapple, citrus	12
4,5-dimethyl-1,3-benzenediol	warm, floral	10
phenyl methanol	roasted then harsh	10, 12
3-hydroxyphenyl methanol	peach, fruity	10
3,4-dimethoxyphenyl methanol	milky, vanilla, pungent	10
2-phenyl ethanol	faded rose	8, 10, 12, 18, 19
3-ethoxy-1-propanol	fruity	12
2-butoxy ethanol	roasted	12
2-phenoxy ethanol	dandelion, burnt wood	12
4-hydroxyphenyl ethanol	fruity	10
2-butoxyethoxy 2-ethanol	musty	12
3-phenyl propanol	floral	10
3,4-dimethyoxyphenyl propanol	herbaceous	10
benzyl alcohol	faint, pleasant fruity	8, 18, 19
p-methylbenzyl alcohol	hyacinth, gardenia	18, 19

TABLE 2 continued.

Compounds	Odors	References
p-α-dimethylbenzyl alcohol	grassy	14
p-α-dimethylphenyl alcohol	faint grassy	18
α,4-methylcyclohex-3-ene ethyl alcohol	light, sweet fruity	14, 18, 19
cis-cinnamic alcohol	warm, balsamic, sweet	8, 10
Phenols		
5-methoxy-2,3-dimethylphenol	herbaceous	10
Ketones		
3-hydroxy 2-butanone	Creamy, fatty	10, 12
2-heptanone	fruity, chemical	10
1-octen-3-one	boiled mushrooms, metallic, fungal, wild mushroom	9, 26, 27
2-octanone	floral, musty	10
3-octanone	fruity, sweet, musty, floral, lavender, sweet ester	4, 9, 10, 12, 19, 27
2-nonanone	blue cheese	10
3-ethyl-4-methyl-3-penten-2-one	potato	10
acetophenone	meal	10
4-methyl acetophenone	warm, floral	10
1-phenyl-1,2-ethanedione	camphorated	10
1-phenyl-1,2-propanedione	cake	10
4-hydroxy-3-methyl 2-phenyl-2-cyclopenten-1-one	chlorophyll, chewing gum	10
p-methylacetophenone	sweet, floral, fruity	14, 18, 19
3,6-dihydro-3-methyl acetophenone	sweet, fruity	14, 18, 19
3-methyl-8-hydroxy 3,4-dihydro (1H) 2-benzopyran-1-one	rubbery, balsamic, floral	10

TABLE 2 continued.

Compounds	Odors	References
Esters		
ethyl acetate	solvent, glue	10, 12
1-octen-3-yl acetate	mushroom, soapy water	27
ethyl heptanoate	floral, fruity wine	10
ethyl octanoate	estery	4, 9, 10
ethyl decanoate	estery	4, 9
ethylhydroxy butanoate	pineapple	10
linalyl acetate	floral, fruity	10
methyl benzoate	floral, heavy, pungent, fruity	8, 10, 12, 18, 19
ethyl benzoate	warm, citrus, floral, fruity	8, 10, 12, 18, 19
methylphenyl acetate	fruity, honey	10, 13, 18, 19
1,3-propanediol diacetate	roasted meal	12
1-octen-3-yl propionate	sweet, fruity, herbaceous, medicinal, mushroom	27
2-phenylethyl acetate	rose	10
methyl-4-methoxybenzoate	floral, hyacinth	10
methyl-*p*-methoxyphenyl acetate	anise	13, 18, 19
methyl salicylate	wintergreen	8, 18, 19
methyl anisate	anise	18, 19
methyl cinnamate	strawberry, fruity, jasmine	10, 30
ethyl cinnamate	fruity	10
Lactones		
γ-butyrolacetone	faint odor	10
γ-hexalactone	floral, herbaceous	10
4-hexanolide	fragrant	4, 9
4-heptanolide	fragrant	4, 9
4-octanolide	coconut	4, 9
4-nonanolide	fruity	9
4-decanolide	peach	4, 9, 12

TABLE 2 continued.

Compounds	Odors	References
2-hepten-4-olide	fragrant	9
2-octen-4-olide	fruity, coconut	4, 9
5-octen-4-olide	coconut	4, 9
6-octen-4-olide	coconut	4, 9
2-nonen-4-olide	fruity	4, 9
5-methyl (2H) 3-furanone	rubber, harsh	10
4,6-dimethyl (2H) 2-pyranone	fruity	10
4-methyl-5-hydroxy hexanoic acid lactone	grassy	10
Aldehydes		
hexanal	freshly cut grass	10
heptanal	oily, fatty	10
nonanal	fatty, floral	10
4-nonenal	watermelon	10
2,4-decadienal	fatty	10, 12
trans-2-octenal	sweet to phenolic	27
benzaldehyde	almond, sweet, phenolic	10, 12, 18, 27
2-aminobenzaldehyde	pungent, bad perfume, strong, sweet fruity, orange blossom	12, 34
p-tolualdehyde	almond	14, 18, 19
anisaldehyde	anise	10, 18, 19
phenyl acetaldehyde	oily, green, floral	10
3,4-dimethoxybenzaldehyde	milky, chocolate	10
Pyrazines	dried mushroom	32
Terpenes		
citronellol	rose	13, 18, 19
nerol	sweet, floral, slightly bitter, rose	13, 16, 18, 19
geraniol	rose, sweet	13, 16
linalool	light, sweet, fresh, citrus, floral	10, 16, 18, 19

TABLE 2 continued.

Compounds	Odors	References
γ-nerolidol	woody, floral warm	10
α-bisabolol	floral	10, 12
lepistirone	iris oil, orange blossom	2
Hydrocarbons		
o/m-diacetyl benzene	rubber	10
α-guaiene	balsamic	10
α-gurjunene	fatty	10
α-muurolene	fruity	10
limonene	citrus	10
β-bisabolene	orange, fruity	10
γ-β-farnesene	warm	10
Miscellaneous		
trans-furan linalool oxide	burnt	10
cis-pyran linalool oxide	herbaceous	10
trans-pyran linalool oxide	herbaceous	10
4-methyl-5-thiazole ethanol	animal, sweet	10
Compound A	balsamic, camphor	10

4. MUSHROOMS KNOWN TO PRODUCE AROMATIC COMPOUNDS

Many mushroom species possess an odor that can be described as "mushroom-like," and this special aroma is an essential part of their appeal. Mushroom-like flavor is due to the presence of aliphatic eight-carbon compounds, although other compounds contribute to the flavor. The mycelium of edible mushrooms cultivated by submerged fermentation can be used for the production of mushroom aroma (29), and this process has been patented (28). Other mushroom species have additional distinct aromas that uniquely flavor foodstuffs (19). Specific mushrooms and the aromatic compounds that they have been shown to produce are found in Table 3.

About 50 volatile compounds have been identified in each of seven edible fresh mushrooms: *Cantharellus cibarius, Gyromitra esculenta, Boletus edulis, Lactarius trivialis, Lactarius torminosus, Lactarius rufus,* and *Agaricus bisporus* (26). The C_8 alcohols and aliphatic methyl ketones (C_5 to C_{11}) together with benzyl alcohol, benzaldehyde, hexanol, and 3-methyl butanol comprise around 90% of the total volatile compounds extracted. General mushroom-like aroma is due to 1-octen-3-ol, formed by the enzymatic breakdown of linoleic acid, while 1-octen-3-one seems to be

TABLE 3. Mushrooms and their aromatic compounds

Mushrooms	Compounds	References
Agaricus bisporus	1-octen-3-ol 1-octen-3-one *trans*-2-octenal *trans*-2-octen-1-ol benzaldehyde benzyl alcohol phenylacetaldehyde octanol 3-methylbutanal 3-octanone 3-octanol 1-octen-3-yl acetate 1-octen-3-yl propionate nonanol furfural	9, 15, 19, 21, 25, 26, 27
Armillaria lutea	3,4 dimethoxyphenyl methanol 3,4 dimethoxy benzaldehyde methyl ketones	10
Armillaria mellea	3,4 dimethoxyphenyl methanol 3,4 dimethoxy benzaldehyde	10
Armillaria ostoyae	1-octanol	10
Auriporia aurea	2-octen-4-olide	15
Boletus edulis	1-octen-3-ol 1-octen-3-one *trans*-2-octen-1-ol *trans*-2-octenal 3-octanol 3-octanone octanol 1-octen-3-yl acetate 1-octen-3-yl propionate nonanol pyrazines 2-formylpyrroles lactones	9, 15, 26, 27, 33
Cantharellus cibarius	1-octen-3-ol 1-octene-3-one *trans*-2-octenal *trans*-2-octen-1-ol 3-octanol	26, 27

TABLE 3 continued

Mushrooms	Compounds	References
	3-octanone octanol 1-octen-3-yl acetate 1-octen-3-yl propionate nonanol	
Ceriporiopsis subvermispora	methyl benzoate methylphenyl acetate linalool linalool oxide phenyl acetaldehyde methyl cinnamate 4-methyl-5-thiazole ethanol ethyl cinnamate *cis*-cinnamic alcohol	10
Clitocybe illudens	sesquiterpenes: δ-cadinol [(+)-torreyol] protoilludane skeleton sesquiterpenes: illudalic acid, illudinine	15, 22, 23
Dichomitus squalens	benzaldehyde 3,4 dimethoxyphenyl methanol 3,4 dimethoxy benzaldehyde	10
Gloeophyllum odoratum	methylphenyl acetate geraniol methyl-*p*-methoxyphenyl acetate nerol citronellol linalool drimenol 1-octen-1-ol 1-octen-3-ol anisaldehyde d-limonene drimenol methyl-3-hydroxy-3,7-dimethyl-6- octenoate	13, 15, 18, 30
Gloeophyllum trabeum	methyl cinnamate sesquiterpenoids compound A	10
Grifola frondosus	benzothiazole 3-methyl-8-hydroxy-3,4-dihydro (1H) benzopyran-1-one	10

TABLE 3 continued

Mushrooms	Compounds	References
Gyromitra esculenta	1-octene-3-one *trans*-2-octenal *trans*-2-octen-1-ol 3-octanol 3-octanone octanol 1-octen-3-yl acetate nonanol	26, 27
Hebeloma sacchariolens	2-aminobenzaldehyde	34
Heterobasidion annosum	4-hydroxy-3-methyl 2-phenyl 2- cyclopenten-1-one	10
Hirschioporus pergamenus	1-octanol 3,4 dimethoxyphenyl methanol 3,4 dimethoxy benzaldehyde methyl cinnamate	10
Inocybe corydalina	methyl cinnamate	15, 31
Inocybe pyriodora	methyl cinnamate	15, 31
Inocybe odorata	methyl cinnamate	15, 31
Lactarius rufus	1-octen-3-ol *trans*-2-octen-1-ol 1-octene-3-one *trans*-2-octenal 3-octanol 3-octanone octanol nonanol	26, 27
Lactarius torminosus	1-octen-3-ol *trans*-2-octen-1-ol 1-octene-3-one *trans*-2-octenal 3-octanol 3-octanone octanol	26, 27
Lactarius trivialis	1-octen-3-ol *trans*-2-octen-1-ol 1-octene 3-one *trans*-2-octenal 3-octanol 3-octanone	26, 27

TABLE 3 continued

Mushrooms	Compounds	References
	octanol 1-octen-3-yl acetate	
Lactarius uvidus	drimenol (a bicyclofarnesol)	15
Lentinellus cochleatus	*trans*-nerolidol fokienol 6-formyl-2,2-dimethylchromene	15
Lentinula edodes	lenthionine 4-methyl acetophenone 3-methyl-8-hydroxy-3,4 dihydro (1H) 2-benzopyran-1-one	5, 10
Lentinus lepideus	methyl cinnamate sesquiterpenes: cadinols muurolols cubenols farnesol drimenol terrestrol linalool geraniol	1, 15, 18, 32
Lenzites betulina	linlool linlool oxides linlool acetate 3-hydroxy-2-butanone 2,3 butanone 2,3-butanediol 3-octanone methyl benzoate 2,4-decadienal	10
Lepista irina	bisabolane derivative: lepistrone	2, 15
Mycoacia uda	*p*-tolualdehyde *p*-methylacetophenone α-4-methylcyclohex-3-ene-ethyl alcohol *p*-tolyl-1-ethanol *p*-tolylaldehyde *p*-methylbenzyl alcohol *p*-α-dimethylbenzyl alcohol iso-butanol 3,6-dihydro-3-methylacetophenone methanol	6, 7, 14, 15, 18, 30

TABLE 3 continued

Mushrooms	Compounds	References
	ethanol iso-pentanol pentanol isopropanol propanol	
Perenniporia subacida	benzaldehyde 1-octanol methyl cinnamate Compound A	10
Phellinus igniarius	benzyl alcohol ethyl benzoate linalool methyl benzoate methyl salicylate phenylethyl alcohol phenol	8, 10, 15, 18
Phellinus laevigatus	benzyl alcohol methyl benzoate methyl salicylate phenylethyl alcohol	8, 15, 18
Phellinus pini	phenyl methanol 3-phenyl propanol	10
Phellinus robustus	1-octanol	10
Phellinus tremulae	benzyl alcohol ethyl benzoate linalool methyl benzoate methyl salicylate phenylethyl alcohol phenol	8, 10, 15, 18
Phlebia radiata	aromatic primary alcohols α-bisabolol1	12, 15
Pleurotus euosmus	linalool coumarine cis- and trans-linalooloxides	10, 15, 18
Pleurotus ostreatusse	squiterpenoids	10
Polyporus betulinus	1-octanol	10
Polyporus durus	2-methyl-1-propanol	4, 5

TABLE 3 continued

Mushrooms	Compounds	References
	3-methyl-butanol 1-hexanol 3-octanol 1-octanol 3-octanone ethyl octanoate ethyl decanoate 4-hexanolide 4-heptanolide 2-hepten-4-olide 4-octanolide 2-octen-4-olide 5-octen-4-olide 6-octen-4-olide 4-nonanolide 2-nonen-4-olide 4-decanolide 4-butanolide 4-pentanolide 2-hexen-4-olide 5-hexen-4-olide 2,5-en-6-octan-4-olide 2-decen-4-olide	
Stereum subpileatum	cinnamic acid derivatives	10
Trametes suaveolens	anisaldehyde benzaldehyde methyl anisate δ-cadinene	13, 18
Tricholoma matsutake	1-octen-3-ol	22
Tyromeces sambuceus	4-decalactone (4-decanolide)	15

important in producing the more specific aroma of cooked mushrooms. The major compounds found in uncooked *Agaricus bisporus* are 3-octone, 3-octanol, 1-octen-3-ol, benzaldehyde, octanol, and 2-octen-1-ol. After cooking, 1-octene-3-one is found in addition to the others (25). The flavor of the shiitake mushroom *Lentinula edodes* is due to a cyclic sulphur compound lenthionine, which is produced during drying and processing (5). An analysis of the dried mushroom *Boletus edulis* showed the presence of approximately 70 constituents, including nine pyrazines and seven 2-formylpyrroles (33).

Gloeophyllum odoratum (=*Trametes odorata*) produces sweet or rose-like citronellol, nerol,

and geraniol, methylphenylacetate with a honey-like odor, and methyl-*p*-methoxyphenylacetate with an anise-like odor. *Trametes suavolens* produces methylanisate, anisaldehyde, and benzaldehyde (13). In the culture broth of several *Phellinus* strains, methylbenzoate was discovered as being the main compound along with methyl salicylate, benzyl alcohol and linalool (8). *Mycoacia uda* synthesizes a pleasant fruity aroma. Thirty-one compounds have been detected in surface cultures of this strain with *p*-tolualdehyde, *p*-methylacetophenone, *p*-α-dimethylbenzyl alcohol, and *p*-methylbenzyl alcohol being the main volatiles (14).

Fruit bodies of *Lentinus lepidus*, which produce a characteristic anise-like odor, contain cinnamic acid derivatives, sesquiterpene hydrocarbons, and alcohols (1, 32). The source of the sweet odor of *Hebeloma sacchariolens* is 2-aminobenzaldehyde (34). The fruity, jasmine aroma of *Inocybe corydalina* and *Inocybe pyriodora* is due to methyl cinnamate (31). The lactones of *Nigroporus durus* (=*Polyporus durus*) have a pineapple or coconut aroma (4).

5. CULTURE CONDITIONS FOR PRODUCTION OF AROMATIC COMPOUNDS

Production of volatiles and the resulting flavors by mushrooms depends on the composition of the growth medium, growth conditions, genetic variation of the strains, and the subjectivity of sensory perception. Modifications of culture conditions, especially the choice of nitrogen and carbon sources appear to influence, at least quantitatively, the composition of the fungal odorous profile. Gallois and coworkers (10) investigated the volatile metabolites produced by 29 ligninolytic strains, representing 22 species, on six different liquid media, two natural and four synthetic, with and without agitation. They identified 113 compounds in 25 strains. Detectable odorous notes generally appeared after seven to ten days and lasted for two to ten days. Aromas were generally more intense in stationary culture. The mycelium morphology in agitated media seems to affect odorous metabolite production; strains that form numerous small pellets of regular size were odorless. One that formed long-hair fur balls produced a strong odor. The production of pigment is sometimes associated with aroma production. At different stages of growth, the same mushroom can produce different odors (3).

Odorous profiles of mushrooms are generally determined through the use of gas chromatography coupled with infrared, mass spectroscopy or nuclear magnetic resonance analysis. Results obtained by different laboratories using the same species often differ in both composition of the profile and the concentration of the volatile compounds. More than 150 compounds have been detected, one-third of which possessed an aromatic skeleton. The most numerous are alcohols, aldehydes, and ketones (10, 19).

6. DISCUSSION

A wide variety of compounds with unique and potent flavor notes have been isolated as naturally occurring metabolites of mushrooms. The aroma profiles for individual strains vary according to the medium used, growth conditions, genetic variation, and sensory evaluation of the investigators. With the help of analytical techniques an increasing number are still being identified and characterized. Further research in this area should be most rewarding.

Although mushrooms produce desirable aromatic compounds, they have not yet become a commercial source of flavor materials. One of the limiting factors is the time required for growth and the low yield of flavor material. Due to the flavor potency of certain flavor compounds, low yields

can be tolerated. Other problems are technical. The volatility and low solubility of aromatic compounds in water makes their recovery difficult. However, aromatic metabolites, which are produced only to a small extent on the natural substrate, can be enormously enriched with the selection of suitable strains and appropriate growth conditions. Purification of flavor compounds from mushrooms that produce complex volatile mixtures can be difficult, but a systematic screening for mushrooms in culture that produce a few primary volatiles could help to solve that problem.

In the search for naturally-occurring flavor substances, strains for screening are available from culture collections. The American Type Culture Collection (ATCC), for example, maintains more than 6,000 authenticated strains of edible and wood-decaying mushrooms from all over the world for use by research and bioindustry.

In addition to opening up new possibilities for the production of aromatic materials, mushrooms can also provide a system for studying the biosynthetic pathways involved in flavor formation. In the future, biotechnologists will be able to choose from a large variety of biocatalysts for the total biosynthesis of aromatic compounds from simple precursors. Further development of these processes, which could translate into billions of dollars worth of flavoring materials for the food and cosmetic industries, depends on a thorough knowledge of mushroom potentialities.

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