The Taste of Mushrooms

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Introduction

THE TASTE AND smell of mushrooms are important for both the identification of species and for the oro-sensory sensations one experiences while eating them. Several issues regarding gustation and olfaction are important to the mycophagist and will be discussed here. First, perceptions of the taste, smell, and texture of mushrooms will be differentiated and discussed. This will be followed by a discussion of sensory deficits that can impair the taste or smell systems and lead to particular problems either identifying or eating mushrooms. Special consideration will be given to those who cannot taste bitter compounds and the potential that exists for these people to misidentify particular species of mushrooms.

The flavor experienced from eating mushrooms, or any other food, comes from a combination of taste, texture, temperature, spiciness, and aromatic qualities (Zasler et al., 1992). Since this review primarily deals with taste, it is important to briefly define and differentiate these concepts. Taste is one component of flavor and is thought to be limited to the perception of sweet, sour, salty, bitter, and savory. See Figure 1 for a chart depicting the components of flavor. Receptors for these five taste qualities are contained in taste buds, which are located on the palate (top of the mouth) and pharynx (back of the throat), as well as the tongue. Despite what is commonly believed, taste receptors on all portions of the oral cavity respond equally well to the different tastants (see Smith and Margolskee, 2001, for a review of this topic).

Savory or "meaty" is the taste quality represented by amino acids, or protein. Foods rich in amino acids include mushrooms, fish, meats, cheese, and some vegetables like kelp and tomatoes. Savory taste is exemplified by a chemical called monosodium glutamate (MSG), which is a common food additive. MSG is composed of an amino acid, glutamate, and sodium, which is an exemplar of salty taste. A second component of flavor is smell. Our olfactory systems are capable of detecting around 10,000 different smells. These various smells, when combined with taste, often yield a unique oro-sensory experience. The last components of flavor are the spiciness, physical temperature, and general texture of the food, which are all signaled by the trigeminal nerve. Spiciness can range from a mild tingly sensation caused by spearmint to the painful burning evoked by a spicy pepper or *Russula emetica*. Mushroom books often use adjectives to describe the "taste" of mushrooms that include all of these components of flavor. Although many mushroom identification books describe the odor or taste of mushrooms as useful diagnostic characteristics, many books unfortunately ignore them. The taste of mushrooms will now be explored in depth, giving specific attention to what contributes to a given taste.

Taste

The taste of *Agaricus bisporus* is often described as "mild" or "meaty" and is best typified by the taste quality "savory" because of its high amino acid content. To account for the taste of this mush-

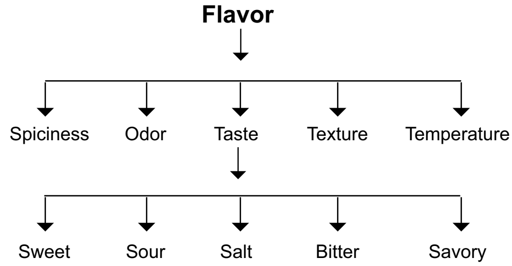

Figure 1. This flowchart depicts the multiple components of flavor as well as the five basic taste qualities.

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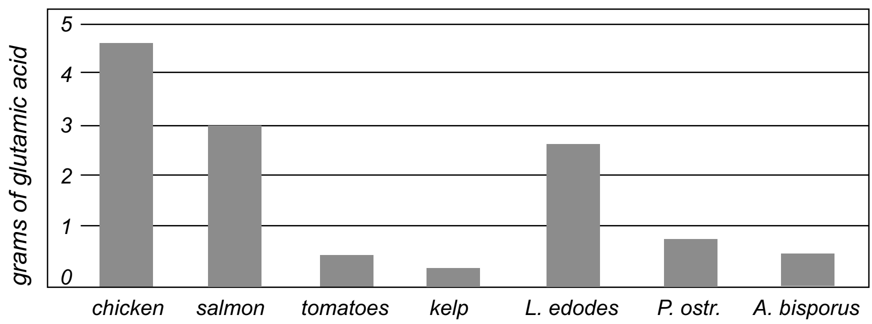

Figure 2: Mushrooms have high levels of glutamic acid. This is a graph that depicts the number of grams of glutamic acid per 100 g of various protein rich meats, vegetables, and fungi. L. edodes, Lentinula edodes; P. ostr, Pleurotus ostreatus; A bisporus, Agaricus bisporus. Data from the USDA.

room, we will explore its components. According to the United States Department of Agriculture (USDA) nutrient data laboratory, 100 g of raw *Agaricus bisporus* contains 92.43 g of water, 3.09 g of protein (amino acids), 0.34 g of fat, 1.65 g of sugars, 1.0 g of fiber, 422.39 mg of minerals, and 7.83 mg of vitamins. This Agaricus species contains all 10 of the essential amino acids (ones that cannot be synthesized by the body), and a total of 18 of the 20 amino acids, lacking only asparagine and glutamine. Importantly, lysine, the most difficult amino acid to obtain in vegan diets, is the fifth most plentiful amino acid in *A. bisporus*. One hundred grams of this mushroom accounts for 6.18% of the daily recommended allowance (based on a 2000 calorie/day diet) of protein, 0.52% of the allowance of fat, and 4% of the daily allowance of fiber. This mushroom thus provides a rich source of complete proteins while being a low-fat food source, and is of particular benefit to those individuals on a vegan diet who need alternate sources of the essential amino acids.

Other commercially available and commonly consumed mushrooms such as *Flammulina veluptipes* (USDA), *Lentinula edodes* (USDA), *Morchella deliciosa* (Rotzoll et al., 2006), *Pleurotus eryngii* (Mau et al., 1998), *P. ostreatus* (Bano and Rajarathnam, 1988), and *Ustilago maydis* (Lizarraga-Guerra and Lopez, 1996) contain similarly high amounts of amino acids. A commonly available commercially available mushroom, *Cantharellus cibarius,* is comprised of 10% protein (Danell and Eaker, 1992). One amino acid in particular, glutamic acid, is present in high concentrations in most of these mushrooms. Figure 2 shows the amount of glutamic acid in several commercially available mushrooms alongside other foods that are traditionally considered rich in amino acids and good examples of savory foods.

MSG and other amino acids are flavor enhancers and increase the palatability (pleasantness) of foods (Bellisle, 1998; Halpern, 2000; Prescott, 2001; Yamaguchi and Ninomiya, 2000). Prescott (2001) had groups of people taste salmon cakes, chicken soup, and spring rolls, both with and without the addition of MSG, and had the participants rate the foods on richness, acceptability, saltiness, sweetness, and natural taste. He found that adding MSG to each of these foods significantly increased subjective ratings of richness and acceptability. Two of the three foods were reported to be saltier with the addition of MSG, while "sweetness" and "natural taste" did not increase. Yamaguchi and Ninomiya (2000) described results from the United States Army, who tested the effects of MSG on food preferences 50 years ago. Of the 50 foods or recipes that they added MSG to, results showed that 28 foods or recipes were improved with MSG, 18 were unchanged, and four worsened. Certain types of foods were improved with the addition of MSG, while other kinds of foods tasted worse after addition of MSG. Meat, fish, and canned vegetables or recipes containing these foods were improved

Figure 3: Mushrooms representative of sweet, sour, bitter, and umami tastes. Tylopilus felleus *(bitter: top left),* Gomphus floccosus *(sour: top right),* Clavariadelphus truncatus *(sweet: bottom left), and* Armillaria mellea *(savory: bottom right). Photo of* C. truncatus *courtesy of Marie Heerkens, other photos courtesy of David W. Fischer/AmericanMushrooms.com.*

by MSG. Interestingly, this indicates that adding MSG to amino acid rich foods further enhances their flavor. This implies that adding mushrooms to other protein rich foods increases overall palatability. Conversely, cereals, milk products, or sweet-flavored recipes were made worse by the addition of MSG. One could posit that adding mushrooms to similar food types would make them unpalatable, but this might best be left to individual experimentation.

Recent research in mushrooms has focused on quantifying the various amino acids present in commercially available mushrooms. Taking this a step further, Mau et al. (1998) examined amino acid and sugar concentrations in three different parts of the king oyster mushroom, *Pleurotus eryngii*. They separately analyzed large fruiting bodies, small fruiting bodies, and the base of clusters of the cultivated mushroom. Although concentrations of amino acids were largely similar between the small and large fruiting bodies, the base of the mushroom contained 56% less amino acids than were contained in the fruiting bodies. Conversely, the base of the mushroom contained 65% more sugars than the large and small fruiting bodies, which contained similar amounts to each other. Although the main fruit body and the base of the mushroom contain different proportions of nutrients, they are both consumable. Appropriately, the authors concluded that both parts of this mushroom should be prepared for the table.

Rotzoll et al. (2006) analyzed the individual chemical components of the common morel, synthesized a solution that contained similar proportions of these chemicals, and then sought to define which chemicals were critical to the natural morel taste. In the first part of their experiment, they isolated 33 taste compounds that were present in the morel, and then determined their concentration in the morel. The 33 stimuli were then divided into categories based on their known taste characteristics: there were five savory compounds, seven "sour and mouth-drying compounds," ten sweet, six bitter, and five salty compounds. Next, they presented the individual compounds to participants to determine whether they were present at detectable or subthreshold levels. Of the 33 stimuli, only one savory compound, five sour/mouth-drying compounds, and one of the sweet chemicals were present at supra-threshold levels; the other 26 stimuli were not detected. The authors concluded that the taste of the morel primarily arose from the seven supra-threshold chemicals. In the second part of their study, they made a composite of all 33 taste stimuli in the same concentrations as the natural morel, and termed this the artificial taste imitate. They took this synthetic mixture and then systematically omitted various groups (e.g. all sweet or sour stimuli) or individual components (e.g. glutamic acid) and examined how the deletions affected the taste of the solution. The elimination of several of these components (e.g. 5` nucleotides, carbohydrates) did not result in any difference in flavor. However, the removal of all the organic acids resulted in less sour and savory taste. Removal of one particular sour/mouth drying stimulus, [?]-aminobutyric acid (GABA), resulted in less mouth drying, less savory taste, and an increased perception of bitterness. Removal of glutamic acid, the only amino acid present at supra-threshold levels, resulted in less savory taste. Interestingly, removal of all the bitter or salty compounds, all of which were present only at subthreshold levels, resulted in a slightly reduced taste intensity and complexity. This finding demonstrated that even the subthreshold taste stimuli contributed to the overall taste quality of the mixture. In conclusion, the taste of the morel is a complex taste made of many chemicals, which likely interact with each other to yield the characteristic morel taste. With this knowledge of the chemical components that comprise the morel taste, one should not be surprised to see a morel-like flavoring substance on the grocery store shelf some day.

Although many common edible mushrooms taste savory, many others typify other tastes. Sour-tasting mushrooms like *Gomphus floccosus* contain acid. Traditionally, sour-tasting foods are associated with spoiled foods, and these foods are readily avoided. *Tylopilus felleus* and *Gymnopilus spectabilis* are two examples of bitter mushrooms. Bitter taste is generally associated with toxic stimuli, and bitter foods are readily avoided as well. The full repertoire of bitter compounds in fungi is still incompletely understood, and warrants further research to uncover whether the bitter compounds in fungi bind to the same taste receptors as bitter compounds from plants. The low amount of sugars found in mushrooms explains why they are generally not characterized as sweet. However, *Clavariadelphus truncatus* and *Cantharellus cibarius* are two species typically described as sweet. Only one mushroom species is reported to be salty. The cap surface of *Aureoboletus gentile,* a European mushroom, is reported to taste salty if it is licked. This seems to be an exception, though, as most mushrooms do not contain salts. Figure 3 depicts mushrooms representative of four out of the five taste qualities.

Other Sensory Components

Trigeminal: Mushrooms described in the field guides with descriptors such as acrid, peppery, or burning, all excite the trigeminal nerve, which innervates the tongue and carries the sensory signals to the brain. *Russula brevipies* and *R. emetica* are good examples, and anyone who has tasted these mushrooms is aware of the burning sensation that overcomes the oral cavity.

Smell: The odors of mushrooms are as numerous as the number of species themselves. Mushrooms vary from the soapy smell of *Tricholoma saponaceum* to the difficult to describe but immediately recognized cinnamon-like odor of *T. magnivelare*.

Sensory Deficits

Deficits in smell and taste are widespread and can present a handicap in mushroom identification and alter the oro-sensory experience of eating them. Common causes of taste and smell deficits will be briefly considered, followed by specific examples of when these deficits can lead to the misidentification of mushrooms. Most people who experience a subjective loss of "taste" actually have smell dysfunctions instead. For example, at the Monell-Jefferson Chemosensory Clinical Research Center (MJC), a total of 547 people complained of taste deficits. Of these, only 48

(8.8%) were found to have measurable deficits in taste (and only two of these people were found to have a complete loss of taste). The overwhelming majority of the people, 366 (70%), had measurable deficits in smell (174 of these people had anosmia, or a complete loss of the sense of smell) (Cowart et al., 1997). A loss of smell often results in a subjective loss of taste, although in strict terms, the patient can still "taste." This is best explained as follows: we have all had experiences of eating while we have a cold and are unable to smell the foods we eat. Although there are marked decreases in the overall perception of the food, and the food is subjectively perceived as bland, strictly speaking, the taste system is unimpaired. Thus, most people who complain of "taste" deficits could likely have olfactory problems.

Olfactory disorders are common, often have sudden onsets, and have several main causes. In a survey of 1.5 million people in 1987, 1.2% of respondents reported permanent olfactory loss and 62.4% a temporary loss of olfaction (Gilbert and Wysocki, 1987). The most common causes of olfactory loss are upper respiratory infections or colds, head trauma, sinus disease, and medication (Doty et al., 1991). Costanzo et al. (2003) reviewed the literature on the relationship between head injuries and loss of olfaction. They found that the incidence of anosmia (a complete loss of smell) was directly correlated to the degree of head trauma; 4–7% of people who experienced mild head trauma were anosmic, compared to 92% of people who suffered severe head injuries. Another common cause of olfactory loss is medication. Mott and Leopold (1991) compiled an extensive list of medications that impair the sense of smell. These causes of olfactory loss are important to know because sensory loss negatively impacts the overall quality of life, not just the ability to quickly differentiate a *Tricholoma magnivelare* and *T. zelleri,* which can look very similar.

Gustatory loss is less prevalent than olfactory loss, but also has profound effects on the quality of life. A loss or decrease of taste function can arise from many causes, but most can be placed in one of three main categories. First, taste dysfunction can result from physical damage to specific taste nerves suffered during surgery or as a result of a traumatic brain injury. Damage can be sustained from cochlear implants (Hamamoto et al., 2000), surgery to remove acoustic tumors (Mott, 1992), surgery to any one of the auditory ossicles (Mott, 1992), and dental surgery (Zuniga et al., 1994). Traumatic brain injuries, which also physically damage the taste nerves, are wide spread; it is reported that one in every 200 people who suffer a traumatic brain injury experience taste deficits (Sumner, 1967). Second, taste dysfunction often results from diseases and the drug treatments used for various conditions. For example, prescription drugs (Schiffman, 1991), radiation therapy, and chemotherapy (Beidler and Smith, 1991) all have effects on the taste system. Third, disorders and diseases, e.g. depression (Amsterdam et al., 1987), bulimia (Rodin et al., 1990), Parkinson's disease (Zucco et al., 1991), and certain genetic disorders (Henkin, 1967) alter normal taste perception. Taste disorders, irrelevant of the cause, impact many facets of life. The above etiologies of taste dysfunction are mentioned because they are common and can cause abrupt changes in the perceived taste of foods. A genetic disorder whereby people are unable to taste bitter compounds has special relevance to mycophagy, and will be discussed in depth below.

Non-tasters: Approximately 25% of the population (Bartoshuk et al., 1998) has a genetic variation in their bitter taste receptors that renders them unable to detect some bitter compounds. These people are therefore at risk for misidentifying bitter mushrooms, especially if they are taught to rely on their sense of taste to distinguish between bitter and non-bitter mushrooms. People with this genetic variation are called non-tasters and they have a diminished ability or complete failure to detect some bitter compounds. A laboratory accident in the early 1930s led a researcher to discover that a compound he was working with was intensely bitter to his lab assistants but not to himself. In 1931 Fox published the first report on non-tasters. He found that six out of ten people in his sample could not taste the bitter compound he tested. More recently, a different, safer bitter compound has been used in taste research to test for non-tasters in the population, and 25% of people cannot taste the compound (Bartoshuk et al., 1998). Kim et al. (2003) has found a mutation on gene TAS2R38 of chromosome 7Q36 in non-tasters. This gene is responsible for making a bitter taste receptor.

It is currently unknown whether various bitter compounds contained in mushrooms

Figure 4: Boletus edulis *(left) and* Tylopilus felleus *(right) look similar and are often confused with each other.* B. edulis *is savory while* T. felleus *is intensely bitter to most people. Distinguishing characteristics: (1)* B. edulis *has white webbing around the stem, (2) the cap is red-brown in* B. edulis *but tan to brown in* T. felleus, *and (3) the pores become yellow-green with age in* B. edulis *but pink in* T. felleus. *Photos courtesy of David W. Fischer/AmericanMushrooms.com.*

bind to the same receptor that is known to be absent in non-tasters. There are numerous bitter compounds in nature, and there also exist several bitter taste receptors that each likely binds a family of structurally similar bitter compounds. However, there is anecdotal evidence to suggest that the bitter compounds in *Tylopilus felleus* and *Gymnopilus spectabilis* bind to the taste receptors that are absent in non-tasters. One person in my own mushroom group is unable to taste the bitterness in *T. felleus*. His son also failed to taste the bitterness, suggesting a genetic factor in their inability to taste the bitter compound. There are also similar stories from other mushroom groups. The percentage of people who cannot taste the bitter compound in *T. felleus* is unknown, and although it could be a result of a mutation on gene TAS2R38, this has yet to be demonstrated. Nearly all mushroom identification books explicitly state that the final definitive step in distinguishing *T. felleus* from other Boletaceae such as *T. indecisus* or *Boletus edulis* is a simple taste test. See Figure 4. The former is strongly bitter while the latter two have a mild more pleasant taste. In light of evidence suggesting that up to 25% of people cannot taste some bitter compounds, recommending a taste test to confirm the identification of some mushroom is potentially dangerous. Although there have been no reports of illness or death from *T. felleus,* I doubt anyone would recommend eating the same quantity of it as many people eat *B. edulis.*

A second potential misidentification of mushrooms based on the lack of a bitter taste is with *Gymnopilus spectabilis*. In a short descriptive account, Roper (2003) harvested *Armillaria mellea* which turned out to be *G. spectabilis*. After this person and one of their friends ate some quantity of these mushrooms, they began to experience hallucinations characteristic of *G. spectabilis* and other hallucinogens. *G. spectabilis* is a very bitter mushroom that is of similar size, shares a similar habitat, and can be a similar color to some forms of mushrooms in the *A. mellea* complex. See Figure 5. The cap color of mushrooms in the *A. mellea* complex can range from the yellow-brown form in Figure 5 to the more typical brown color represented in Figure 3. The only way for someone to be unable to taste the bitterness in *G. spectabilis* is if they are a non-taster. This story is interesting because there were two people who were eating the mushrooms, and presumably, both could not taste the bitterness. If the incidence for a non-taster for this compound in the population is 25%, then the odds of any two unrelated people chosen at random being non-tasters is 1 in 8, or 12.5%. These are not small odds, underscoring the importance of educating mycologists and mycophagists about this issue. The short account concludes that there may be a new species of *G. spectabilis* that is not bitter. Wishful thinking aside, I believe it more likely that the consumers of the mushrooms were non-tasters.

Figure 5: Gymnopilus spectabilis *(left) and mushrooms in the* Armillaria mellea *complex (right) can look similar and share similar habitats.* G. spectabilis *is intensely bitter, while* A. mellea *and allies is savory. Distinguishing characteristics: (1)* G. spectabilis *is yellowish-orange while* A. mellea *is yellowish-brown, and (2)* G. spectabilis *has an orange-brown spore print, while A. mellea has a white spore print. Photo of* G. spectabilis *courtesy of Hugh Smith, and* A. mellea *courtesy of Rex Bartlett.*

Deficits with Aging: The perceived intensity of salty and bitter tastes decrease as a function of age. First, Weiffenbach et al. (1982) assessed the detection threshold of NaCl (salty) in young, middle, and old participants. The young group consisted of people less than 45 years old, the middle group people between 46 and 65 years old, and the old group consisted of people older than 66 years old. They found that the millimolar concentrations of NaCl in a taste solution needed to reach detection threshold were 2.49, 3.26, and 6.09 in young, middle, and old participants, respectively. Second, Cowart et al. (1994) found that older people (mean age 74 years old) rated quinine (bitter) as less bitter than younger people (mean age 26 years old). These deficits likely alter the subjective experience of eating food. The taste experience from the same mushroom may not be same between a young and old person, but palatability still remains a matter of taste.

Conclusions

The sense of taste and smell is important to the identification of mushrooms. First, this review explained the common tastes of mushrooms, and the specific components in mushrooms that yield different tastes. Second, this review described common taste and smell deficits that impair the perception of some mushrooms, as well as discussed specific taste-related deficits with aging. Research has demonstrated that bitter and salty taste is compromised with the normal aging process. A decrease of salty taste is likely of little importance in tasting mushrooms because mushrooms are not naturally salty. However, elderly people should be aware that there is a decrease in the perceived intensity of some bitter compounds with age. Interestingly, deficits in the perception of savory taste stimuli with aging have not been studied. Other deficits to taste and smell typically come from physical damage to the sensory systems or from genetic causes, and this short review has described the most prevalent ones. It is the aim of this review that mushroomers are educated about the importance and individual variation of perceptions of taste and smell of mushrooms. For example, a mushroom might be described as tasting very bitter to one person, somewhat bitter to an elderly person, and not bitter at all by a non-taster. Importantly, these individual variations can lead to the misidentification of specific mushrooms. This review has described a few specific examples where specific taste or smell disorders can lead to the misidentification of particular mushrooms, but it is likely that many more exist, underscoring the role of educating mushroomers about these issues.

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