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ESSAY

Umamification of food facilitates the green transition

Ole G. Mouritsen

Department of Food Science, Taste for Life, Design and Consumer Behavior, University of Copenhagen, 26 Rolighedsvej, DK-1958 Frederiksberg, Denmark

The planet is facing a global climate crisis. Measures have urgently to be taken to alleviate the consequences by diminishing emission of greenhouse gases, cutting fossil energy consumption, and implementing sustainable uses of the world's resources. Being responsible for more than one third of the stressors on the climate, the global food production systems and our eating behavior must change dramatically (Vermeulen et al., 2012).

International high-level reports (Willett et al., 2019; Searchinger, 2019), in alignment with the United Nations Sustainable development goals (2019), have presented a solution, however fragile, to a so-called 'planetary menu' that can feed a global population approaching 9.8 billion people in 2050 a healthy and nutritious diet that is also sustainable. The proposed menu includes 500 g vegetables and fruit every day and little or no red meat. Specifically, the planetary menu consists mainly of vegetables, fruit, whole grain, legumes, nuts, unsaturated fats, only moderate or small amounts of fish and poultry, and no, or very little red meat, processed meat, added sugars, refined cereals, and starchy vegetables. The bottom line is that we must eat more plant-based foods and less meat corresponding to an 86%:14% caloric ratio for plant-based foods compared to animal-based foods (Willett et al., 2019). For many populations, e.g., in Europe, this implies a cut by 80% in the average daily meat consumption.

It has been pointed out that such dramatic changes cannot take place without a focus on the taste of food (Schmidt and Mouritsen, 2020), taking the naïve but obvious position, that no food can be considered sustainable before it is eaten. Food not eaten must be considered as waste. Paradoxically, the high-level reports mentioned above, as well as most national dietary recommendation programs, do not talk about taste or flavor. I believe the reason for this is that the authorities and many experts do not recognize the difference between physiological taste and taste preference (the hedonic taste). Whereas hedonic taste is determined by a wide range of individual, social, (food)-cultural, psychological, traditional, and ethnic circumstances, the physiological taste, as described by the five basic tastes (sour, salty, bitter, sweet, and umami), is mediated by receptors and neural circuitry that obey the universal laws of nature and in principle can be measured quantitatively and be related to certain chemical compounds in the foodstuff.

And here it turns out, that being faced with eating more plant-based food we are up against some fundamental properties of plants on the one side and *Homo sapiens*' evolutionary determined and genetically encoded taste preferences for sweet and umami (Schmidt and Mouritsen, 2020). Humans have evolved as omnivores and steered by the co-evolved senses and associated receptors to seek out food that is good for survival and avoid food that may be dangerous. We are designed to seek sweetness, because sweetness signal sugars, and sugars imply calories that are good for survival. Having been meat eaters for at least two million years, particularly so after starting using fire (Wrangham, 2009), we also seek umami (Dunn and Sanchez, 2021). Umami signals proteins (free amino acids, in particular glutamate) that are good for nutrition and provide energy. Furthermore, muscles from meat contain large amounts of nucleotides that enhance the umami taste (so-called umami synergy).

Humans' universal quest for sweetness and umami is hence in our genes. This is not a matter of individual taste preferences and culture. At the same time, we generally steer away from bitter tastes since they signal poisonous foodstuff. It is important to note that I do not say that humans have a craving for meat as such but a craving for the *taste* of meat, i.e., umami. This is an important distinction and a key to the green transition.

Turning then to plants, it is typical that the roots, stems, foliage, flowers, and unripe fruits have very little sweetness (the sugars are bound in tasteless carbohydrates) and very little umami (the free amino acids are bound in tasteless proteins). Furthermore, plants do not have muscles to accumulate adenosine triphosphate that is a source of free nucleotides. At the same time, plants (except for the ripe

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E-mail address: ole.mouritsen@food.ku.dk

fruits) may be bitter in order for them to deter animals from eating them.

So, this is the challenge we are facing when confronted with eating more vegetables and less meat. But once that being said there is also a solution. The solution is to impart to green dishes the 'missing' tastes, in particular umami, or release the plants' own potential to develop umami and sweetness from their proteins and carbohydrates, respectively. The latter is conveniently done by fermentation using microorganisms like bacteria, fungi, and yeast, or the enzymes from such organisms (or industrially produced enzymes).

The solution to 'umamify' green foodstuff as described above (Mouritsen and Styrbæk, 2020; Schmidt and Mouritsen, 2022) is well-known to many food cultures, although it is seldom put in words as I have done here, drawing on fundamental plant biology and aspects of human evolution. Also, the use of what we now know are umami-rich condiments mostly belongs in the realm of cooking traditions, silent experience, and craft, rather than science. When it comes to verbalize what umami is, it is mostly Asian food cultures that traditionally have used specific expressions for this type of taste sensation, such as *xiān wèi* in Chinese, *dam da* in Vietnamese, and *gamchil-mat* in Korean. However, these terms are often erroneously used synonymously with 'delicious.' Whereas umami implies deliciousness, deliciousness need not alone be elicited by umami but can arise by a combination of the four other basic tastes along with aromas.

In any case, pescatarian, vegetarian, and vegan food cultures all have found their preferred condiments to impart to vegetable dishes with what we now would call umami by using umami-rich ingredients such as fungi, tomatoes, eggs, yeast, certain seaweeds, as well as various fermented products, like soy sauce, fish sauce, and cheese (Mouritsen and Styrbæk, 2014), cf. Figure 1. Meat eaters also know how little cured ham, beef jerky, and bacon is needed to help a green dish along, not to speak about meat stocks and sauces.

In a recent Essay, Yong-Guan Zhu (2022) has described his personal experiences with Chinese food culture, highlighting that the Chinese in recent decades have markedly increased their consumption of meat (particularly chicken) and apparently forgotten the ancient wisdom of stir-fry-cooking of vegetables flavored with only little meat or fungi. Similarly, he points out how basic soups, soup stocks, as well as soy sauce have made traditional Chinese cuisine very green. Zhu's type of reflections over a traditional and more sustainable food culture are most welcome and enlightening and should inspire to rediscover and revive in other food cultures the nearly forgotten insights of a more sustainable eating behavior.

In this context the following example may serve as an inspiration. Both Chinese and Japanese food cultures have

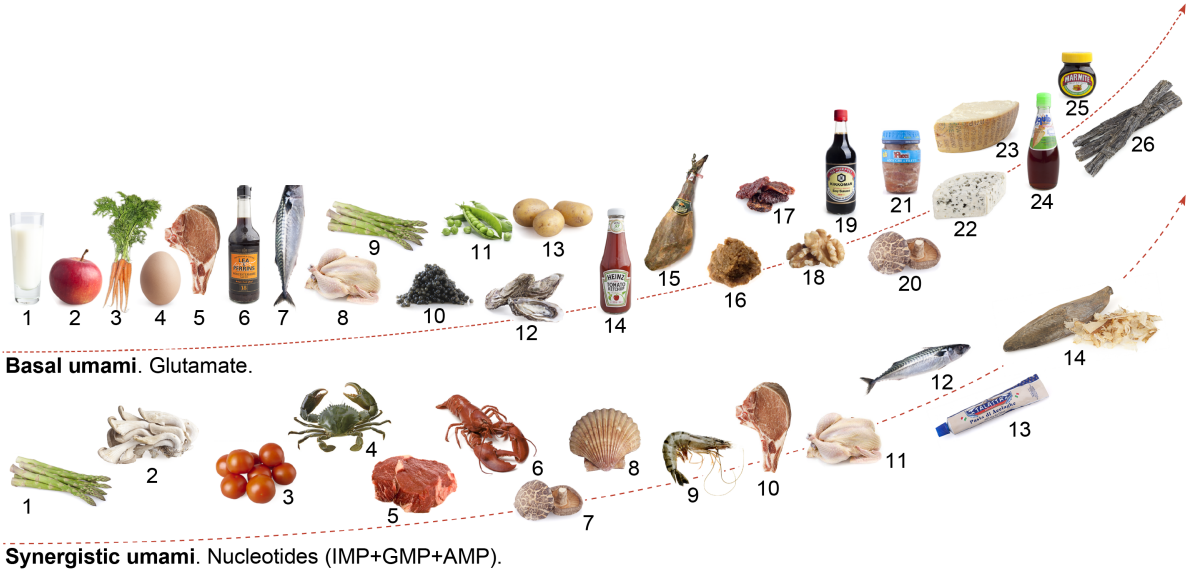

Fig. 1 A representative selection of raw ingredients and processed food products that contain umami taste substances, ranging from very small quantities (on the left) to an abundance (on the right). The products on the top elicit basal umami from free glutamate, while those on the bottom elicit synergistic umami from the free 5′-ribonucleotides inosine monophosphate (IMP), guanosine monophosphate (GMP), and adenosine monophosphate (AMP). Note that the horizontal axes are not linear, and the position of a given product on the axis does not correspond to its absolute content of umami substances. However, the individual products on each axis are placed in the correct relationship to each other. Top panel: Basal umami. 1: cow's milk, 2: apple, 3: carrots, 4: egg, 5: pork, 6: Worcestershire sauce, 7: mackerel, 8: chicken, 9: green asparagus, 10: caviar, 11: green peas, 12: oysters, 13: potatoes, 14: ketchup, 15: air-dried ham, 16: miso paste, 17: sun-dried tomatoes, 18: walnuts, 19: soy sauce, 20: dried shiitake mushrooms, 21: anchovies in brine, 22: blue cheese, 23: Parmesan cheese, 24: fish sauce, 25: Marmite, 26: dried seaweeds (*konbu*). Bottom panel: Synergistic umami. 1: green asparagus, 2: oyster mushrooms, 3: sun-ripened tomatoes, 4: crab, 5: beef, 6: lobster, 7: dried shiitake mushrooms, 8: scallop, 9: shrimp, 10: pork, 11: chicken, 12: mackerel, 13: anchovy paste, 14: *katsuobushi*. Adapted from Mouritsen and Styrbæk (2014).

for hundreds of years used a particular mold, *koji* (in Japanese) and *qū* (in Chinese), to ferment foodstuff of both plant and animal origin. *Koji* is a culture of a microscopic fungus, *Aspergillus oryzae*, that contains a host of enzymes. These enzymes can break down proteins into flavorful free amino acids, carbohydrates into sweet sugars, and lipids into aromatic fatty acids and other compounds. Traditionally *koji* is used in the production of soy sauce, miso, and sake, and its effect on bitter vegetables is almost magic (Mouritsen and Styrbæk, 2021). Many chefs and restaurants in the West are now using *koji* to ferment protein-rich local pulses and legumes to produce umami-rich condiments similar to soy sauce and miso. A salt-inactivated and easy-to-use culture of *koji* in the form of *shio-koji* can come in as handy and convenient means in ordinary households for increasing the use of vegetables on the expense of meat without compromising the craving for umami taste.

Finally, it should be pointed that there is a bonus with adding umami taste to food which has to do with fundamental aspects of multimodal taste perception. It is well-known that increasing the umami taste at the same time increases sweetness perception (without adding sugar), increases salt perception (without adding more table salt), and finally lead to a dampening of the sensory perception of bitterness (Mouritsen and Styrbæk, 2014). All these assets testify to the fact that umami is a key concept for healthy eating behavior and may come to play an important role in the green transition in our food systems and facilitate the necessary changes in our eating behavior.

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