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Design and 'umamification' of vegetable dishes for sustainable eating

ABSTRACT

Food production is a main cause of the accelerating anthropogenic changes in the Earth's ecosystems. There is an urgent need for global changes in the food production systems throughout the food chain as well as a call for a significant reduction in food waste. Sustainable and healthy eating has hence become a key issue on the global scene. The provision for a sustainable green transition involves eating more plant-based foods. The question then arises if such foods, e.g. vegetables, are sufficiently palatable for the carnivorous human whose evolution has been driven by meat-eating and a craving for umami taste for more than two million years. Is green food sufficiently delicious for us to eat more of it? This article describes an approach to sustainable eating of vegetables based on a combination of gastrophysical insights with culinary innovation and gastronomic design. Plant-based raw ingredients often lack the basic tastes umami and sweet and also need special attention regarding mouthfeel. As a result, a 'taste rack' of condiments, a kind of generalized spice rack or tasting inventory, which allows most vegetables to be turned into delicious dishes by 'umamification' and used effectively in a flexitarian setting, is developed. The power of the approach is illustrated by a number of case studies.

KEYWORDS

vegetables
sustainable eating
umami
kokumi
mouthfeel
flexitarian

INTRODUCTION

The 2019 EAT-Lancet Commission on Healthy Diets from Sustainable Food Systems has analysed the conditions for providing for a healthy, nutritious and sustainable diet for a global population that reaches ten billion people in 2050 (Willett et al. 2019). The report concludes that food production is a main cause for the anthropogenic changes in the Earth's ecosystems, including climate changes, and that there is an urgent need for global changes in the food production systems. At the same time, the commission recommends food waste be decreased by 50 per cent, and that sustainable measures be implemented in the entire food chain from production and processing to consumption. Generally, the commission proposes a diet with more plant-based food, including 500g vegetables and fruit every day and little or no red meat. The specific recommendations involve a diet consisting of mainly vegetables, fruit, whole grain, legumes, nuts and 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. With this recommendation, it should be possible to meet the United Nations Sustainable Development Goals (United Nations 2019).

It should be pointed out that an important constraint on the calculations for providing a diet for an increasing global population is that the food not only has to be sustainable, but also nutritious and healthy. It is a paradox that the current global production of food has enough calories to feed everyone, but at the same time 820 million people are starving and two billion people suffer from diet-related diseases (Searchinger 2019; Willett et al. 2019). First, the distribution of food is very uneven across the globe, and second, modern diets are often dominated by a high consumption of energy-dense foods, refined foods, animal foods, oils and fats, as well as too much salt (Sproesser et al. 2019). Recent meta-analyses indicate a correlation between ultra-processed foods and the risk of cardiovascular disease as well as all-cause mortality (Rico-Campà et al. 2019; Srour et al. 2019).

The proposal for eating a greener diet with more plant-based foods, in particular vegetables, immediately raises the question if such a diet is sufficiently palatable for the carnivorous human whose evolution has been driven by meat-eating and a craving for umami taste for more than two million years (Wrangham 2009; Schmidt and Mouritsen 2020). Is green food sufficiently delicious for us to eat more of it? Only by addressing this fundamental condition of living will it be possible to envision a full-fledged green transition.

There are two fundamental reasons why humans have difficulty with eating plants (Schmidt and Mouritsen 2020). One has to do with the biology of the plants. The other one has to do with human evolution as alluded to above. The biology of the plants enters because, not being able to run away, plants have developed defence systems with bitter and often poisonous substances that are

designed to scare plant eaters away. At the same time plant tissues generally lack a sweet taste because their sugars are bound in carbohydrates that have no taste. This is true of the green parts, stems and leaves, the root, as well as the unripe fruits (McGee 2004). In contrast, the ripe fruits are supposed to be eaten in order to provide for plant reproduction and hence they are soft, sweet, imbued with attractive aromas, and some of them, such as tomatoes, have an umami taste. In addition, plants, not having muscular tissues, have much lower levels of ATP in contrast to animals. Since ATP is a source for forming free nucleotides that elicit umami taste by entering a synergistic relationship with basal umami, plants also have less capacity for providing umami taste.

So unprocessed plant food has little to offer when it comes to sweet and umami. This is a challenge for humans who in the course of evolution have come to crave exactly these two basic tastes and at the same time primed to steer away from bitter tastes. A craving for sweet has been with us since our distant ancestors were seeking out aromatic and sweet fruits as their main sustenance. Sweet is a signal of sugars and hence calories, which is good for survival. The craving for umami has evolutionary advantages since it is a signal for proteins and good nutrition. Our preference for umami was developed along with our ancestors' meat-eating practices for the past more than two million years and strongly enhanced after our ancestors learned how to use fire 1.9 million years ago (Wrangham 2009). Umami taste is a common trait of meat and, in particular, prepared meat.

Eating more plant-based foods causes problems not only from the point of view of taste but also nutrition, in particular when those foods enter a complete vegetarian or vegan diet. There are a number of essential nutrients that are either impossible or very difficult to get from plant-based food, in particular vitamin B_{12}, vitamin D_3 (cholecalciferol), taurine, creatine, carnosine, haem-iron, as well as certain super-unsaturated fatty acids (in particular docosahexaenoic acid). Some of these nutrients can be obtained if a pure plant-based diet is supplemented by fungi and algal products. Still, the most effective way involves incorporating elements and condiments of food from the animal kingdom, such as egg, milk products, and small amounts of meat and particularly food of marine origin, such as fish, shellfish, molluscs and algae.

A SOLUTION TO EATING MORE PLANT-BASED FOOD

So, the route to eating more plant-based food is marred with obstacles caused by fundamental plant biology and key elements of human evolution. We are faced with the task of eating 500-600g vegetables and fruit every day, and most vegetables lack sweetness and umami. Umami is a basic taste (along with sweet, salty, bitter and sour) well-known from mature hard cheeses, ripe tomatoes, cured meat, fungi and marine products. A solution that uses scientific insight and culinary skills to design and 'umamify' vegetable dishes, so they become more delectable in terms of taste and mouthfeel, is proposed. By combining science and culinary arts, it should be possible to further a green transition along the lines of the EAT-Lancet Commission's recommendations.

In principle, there are three routes to tackle the problem. One route is to extensively process and engineer plant material, e.g. using enzymes, to improve the flavour and nutritional profiles, with the risk that the food becomes unhealthier (Rico-Campà et al. 2019). Another route, which is the one well-known from many Asian cuisines, is based on adding in particular umami (Mouritsen and Styrbæk 2014) and kokumi substances (Nishimura

and Kuroda 2019) to raw or mildly processed plant food, e.g. using condiments and sauces. Kokumi is a taste sensation covering mouthfullness and continuity and known from garlic, fish sauces and other fermented products.

The most powerful way of imparting umami and kokumi involves marine food sources such as macroalgae, fish, shellfish and cephalopods (Mouritsen and Schmidt 2020), particularly in fermented form (Mouritsen et al. 2017). An additional benefit of using marine food sources as condiments is that they contribute certain essential nutrients that plants lack (e.g. super-unsaturated fatty acids and vitamin B_{12}). Moreover, it is possible to use marine waste products, or little and poorly used marine species, as marine sources to impart flavour to plant food. The third route is in principle a hybrid of the two other routes, where fermentation processes, e.g. by yeast, bacteria or their endogenous enzymes, are used to prepare plant material so carbohydrates and proteins are broken down into sweet sugars and umami- and kokumi-tasting free amino acids and peptides (Mouritsen 2018; Mouritsen and Styrbæk 2020). Fermentation to impart desirable flavour is also a way of turning waste vegetables into edible foodstuff.

Below, a 'taste rack' to increase 'umamification' and to impart a crunchy mouthfeel to vegetables and vegetable dishes using umami and kokumi is introduced. After having described the various elements at the 'taste rack', some case studies that illustrate their use in some selected cases are presented. These cases highlight the need for, and power of food design and innovation based on taste and texture (Mouritsen and Styrbæk 2017) for making delicious dishes of some vegetables that often are discredited due to their inherent taste and texture.

'TASTE RACK' OF CONDIMENTS FOR 'UMAMIFICATION' AND CRUNCHY MOUTHFEEL

The 'taste rack' was constructed as a selection of ingredients and preparations that are known to contribute umami, kokumi, and/or a crisp/crunchy texture to vegetable dishes. Obviously, this is a limited selection and many more could be added, e.g. drawing from the world cuisine. Many of the ingredients are inspired by Asian, and in particular, Japanese condiments and sauces (Mouritsen 2018; Styrbæk and Mouritsen 2020; Mouritsen and Styrbæk 2020). Some of the ingredients are commonly available in most kitchens, some can easily be purchased commercially, and some can readily be home prepared in larger quantities and stored for later use.

Aïoli

Aïoli is a variant of mayonnaise made with garlic. Certain tripeptides in the garlic leads to a kokumi sensation. Although most commonly used with shellfish, aïoli is excellent as a dip to raw vegetables.

Taste and aroma: Salt, kokumi, garlic taste and aroma (sulphuric compounds).
Texture: Creamy.

Anchovies/anchovy paste/anchovy sauce

Salted anchovy filets (*Engraulis encrasicolus*) and anchovy paste are prominent ingredients in many Mediterranean dishes where the anchovy's large content of glutamate and inosinate provides a very strong umami synergy. Salted

anchovies also enter ketchup and Worcestershire sauce and can be used to impart umami and salty taste to all forms of vinaigrette, dressing, marinade, pesto and sauces (such as *bagna càuda*) to be used with vegetable dishes.

Taste and aroma: Umami, salt, marine aroma, often with a sharp smell of oxidized fatty acids.
Texture: Filet is firm and succulent; paste is creamy.

Bacon

Bacon is salted and cured meat from land animals, typically pork, but also beef, poultry and game, which is also cold smoked in some cases. In the case of pork, it can contain more and less fat. Salting proceeds by either wet or dry salting, and often nitrite is added for the sake of conservation or red colouring. In the case of wet salting, different ingredients can be included to add flavour, such as spices and tomato. Smoking with different kinds of wood impart varying aromas. Bacon can be added raw, fried and boiled to impart flavour to vegetable dishes, not least umami.

Taste and aroma: Salt, umami, smoky aroma.
Texture: Firm, chewy, crispy, fatty, melting.

Balsamic vinegar

Balsamic vinegar is a special kind of vinegar that is made from the juice from grapes that have been reduced and subsequently stored in wooden barrels, at least one year and often for decades, e.g. by use of the solera technique. It is often used with green salads, raw vegetables and fresh fruit.

Taste and aroma: Umami, sweet, sour with a very complex taste. Aroma compounds from the wooden barrels.
Texture: Viscous, sticky.

Blackened onions

Blackening or firing onions, or other species in the *Allium* family, such as leeks, gives rise to formation of pyrolysis products and Maillard compounds. Roasted or fried onions have a milder taste than blackened onions and by roasting with sugar there is basis for caramelization. Excellent for flavouring and colouring dark bouillons.

Taste and aroma: Burned, kokumi, taste and aroma from Maillard compounds; possibly caramel flavours.
Texture: Soft, crisp edges.

Black/fermented garlic

Black garlic is formed by preparing fresh garlic at 60–80°C with a humidity of 70–80 per cent for four to six weeks. During this time the white garlic

turns black and the characteristic sharp garlic flavour almost disappears and the garlic becomes mild and sweet with notes of balsamic vinegar and tamarind. At the same time Maillard compounds are formed. The texture becomes creamy. Black garlic can be chopped and sprinkled on green dishes and salad or ground and dispersed in a dressing or sauce.

Taste and aroma: Kokumi, umami, mild, a little acid, sweet, and notes of balsamic vinegar and tamarind. Flavour from Maillard compounds.
Texture: Soft, creamy, and a little waxy.

Blue skim cheese

Blue skim cheeses are made with a culture of *Penicillium roqueforti,* e.g. French roquefort, English stilton, Italian gorgonzola, and Danish danablu. Some cheeses are firm, dry and crumbly; others are soft and creamy. During maturation, the cheeses develop large amounts of free amino acids and peptides with umami and kokumi taste. Due to their delicate and complex flavour spectrum, blue skim cheeses are used in dips and dressings for vegetables or crumbled in green salads.

Taste and aroma: Umami, kokumi, sour.
Texture: Creamy; dry and crumbly.

Botargo

Botargo is dried fish roe in their sacs, typically from tuna, cod fish and mullet. They are a delicacy in Spain (botargo) and Italy (bottarga). Like other fish roe, botargo has a rich umami taste from glutamate. Botargo can be shaved similar to parmesan cheese over green dishes and salads.

Taste and aroma: Umami, salt, some bitterness depending on type of roe.
Texture: Firm, waxy.

Bouillon

A bouillon is a soup broth, fond or aqueous extract of, e.g. vegetables, fungi or meat and bones from animals, poultry, fish or shellfish. Japanese *dashi* is a broth made from *konbu*-seaweed (*Saccharina japonica*) and a fish product called *katsoubushi* (or alternatively dried shiitake in a vegan *dashi*). The combinations of vegetables/meat/bones, vegetables/fungi and *konbu*/*katsuobushi*/shiitake provide for optimal umami synergy. Bouillons can be used as the base for a variety of sauces, marinades and condiments to add umami and other flavours to vegetables.

Taste and aroma: Umami, possibly aromas from added spices.
Texture: Liquid with a consistency depending of the fat content.

Bread

Roasted or fried small pieces of bread or breadcrumbs can be made from leftover bread. They can be stored for some time and easily activated on a hot frying pan before use, e.g. as croutons or breading. The airy structure of Japanese *panko* implies, that when used as breading, the crust becomes very crisp and does not easily absorb grease.

Taste and aroma: Sweet, taste and aroma from Maillard compounds.
Texture: Crisp, crunchy.

Capers

Capers or capers berries are pickled flower buds from the capers bush (*Capparis spinosa*). The unmatured flower buds are pickled in salt and vinegar and become capers, whereas the larger and mature fruits become capers berries. Capers can be deep fried and then become very crisp. Capes have some umami taste and a slightly sharp taste due to the development of isothiocyanates as in mustard. Capers can be used in sauces, dressings, salads and many green dishes.

Taste and aroma: Salt, sour, sharp.
Texture: Capers: juicy and succulent. Capers berries: firm and crunchy.

Cephalopods

Cephalopods (octopuses, squid and cuttlefish) have a flesh (mantle, arms and tentacles) that are sweet and with a fine umami potential. They are low in fats and rich in proteins. Since the muscular structures are meat with a meaty texture, they can in small amounts add meatiness to vegetable dishes and salads. The liver (hepatopancreas) has a strong umami taste and a complex flavour. Therefore, it can be used for flavouring sauces and marinades. Marinated and dried, possibly also cold-smoked, mantles and fins of squid can be shaved over vegetable dishes and salads, similar to botargo and parmesan cheese.

Taste and aroma: Umami, salt, possibly smoky.
Texture: Firm and meaty. In some preparations, possibly chewy or creamy.

Chili

Chili is the second most used spice after salt, and black pepper is third. Chili is not a pepper although it is often called chili pepper or pepper fruit. Chili belongs to the *Capsicum* genus that is a member of the nightshade family (Solanaceae). Chili leads to a strong, irritating and burning/hot sensation (chemesthetic action, trigeminal sensation) that is caused by certain compounds called capsaisinoids that interfere with the mucosal membranes in the mouth. There are a large number of species and hybrids of *Capsicum* and they have very different grades of hotness. Cayenne pepper is one of the milder forms of chili. Chili is conveniently kept as a dry powder or granulate. The strength (hotness) of chili is traditionally measured in Scoville Heat Units

(SHU). On this scale, Jalapeño has 35.000 SHU, Anaheim 1000 SHU, and an ordinary snack chili 0 SHU. Chili is a common spice used to add hotness to marinades, dressings and sauces to go with vegetable dishes.

Taste and aroma: Fruity, strong, hot, burning.
Texture: Crisp and juicy as raw, dry and granulated when dried.

Citrus

There is a large number of species, hybrids and cultivars of the *Citrus* genus. Common ones include lemon, orange, lime, pomelo and grapefruit. Less common are bergamot and *yuzu*. They are all characterized by acidity from citric acid and aroma from limonen but apart from that they differ in sweetness and a variety of aroma compounds. *Yuzu* is particularly suited to flavour vegetables, e.g. as a key ingredient in *ponzu*. The rind of citrus fruits is particularly rich in aromatic oils and when organic it can be used both as a flavouring agent imparting acidity and aroma. Citrus fruits can also be fermented and salted and used as condiments. The citrus juice is often used in dressings, marinades and sauces. The dried rind of *yuzu* enters in certain mixed spices, such as *shichimi*.

Taste and aroma: Sour, somewhat bitter, aroma from limonen.
Texture: Liquid, possible as pulp. The fresh rind is soft and juicy, but also sometimes dry.

Crumble

Crumble can be made from baking a dough of acorn or bean flour which is subsequently broken into appropriate pieces. The crumble goes well with green salads and warm vegetable dishes.

Taste and aroma: Slightly buttery and nutty.
Texture: Crunchy and crisp.

Dashi

Dashi is made as an aqueous extract of *konbu*-seaweed (*Saccharina japonica*) and bonito fish flakes (*katsuobushi*). First *dashi* (*ichiban dashi*) and second *dashi* (*niban dashi*) refer to first and second extraction, respectively. The first *dashi* has the mildest and most delicate taste and aroma. *Konbu-dashi* is an extract made of *konbu* alone. *Shojin dashi* is a vegetarian/vegan *dashi* where dried shiitake is used instead of *katsuobushi*. *Dashi* is the mother lode of umami in Japanese cooking. Due to an interaction between glutamate from *konbu* and inosinate/guanylate from *katsuobushi*/shiitake, *dashi* exhibits perfect umami synergy. *Dashi* keeps in the refrigerator for a couple of days but is best freshly made. *Dashi* can also be made from commercial powder products. *Dashi* enters Japanese condiments like *ponzu* and *sanbaizu*. *Dashi* can be used in dressings, marinades and sauces along with vegetables.

Taste and aroma: Umami, lightly smoked, marine aroma.
Texture: Liquid.

Fish flakes

Fish flakes are small flakes of dried, typically lean, fish. Flakes or strips of dried fish can contribute both texture and flavour to vegetable dishes, not least umami. The flakes can be used in soups, sprinkled over salads, and with both cold and warm vegetable dishes. A special type of flavourful fish flakes is derived from *katsuobushi.*

Taste and aroma: Umami, salt.
Texture: Dry, possible chewy.

Fish sauce

Fermented sauces of fish, shellfish and molluscs are common throughout South East Asia. The production involves salting and fermenting of whole fish or parts of fish, such as blood and entrails. Anchovies enter most fish sauces. The fermentation proceeds by means of the fish's own intestinal enzymes, and the process is often kickstarted by adding the hepatopancreas (liver) from squid. In this process, a large amount of free amino acids and peptides are formed, leading to umami and kokumi flavour. Most sauces contain large amounts of salt. The antique garum is a type of fish sauce. Fish sauces contain no free nucleotides. Fish sauce can be added to dressings and sauces used with vegetable dishes.

Taste and aroma: Umami, kokumi, salt, notes of nuts and cheese.
Texture: Liquid and slightly viscous.

Fungus powder/salt

Fungus and mushrooms like shiitake, funnel chanterelle, porcine and other dark edible fungi can be dried and subsequently ground into a powder or fine granulate. During drying, guanylate is formed which is the basis for umami synergy. When mixed with flaked salt, the fungus powder becomes a fine flavour giver to vegetable dishes and in sauces, dressings and soups.

Taste and aroma: Umami, salt.
Texture: Dry and granulated.

Garlic

Garlic (*Allium sativum*) is commonly used to flavour all sorts of plant-based foods. The particular garlic aroma arises when the garlic is crushed or cut, causing an enzyme (alliinase) to be released which breaks down the compound alliin to allicin. It is allicin that we associate with the flavour of fresh garlic. When heated, the enzyme is destroyed, and the garlic aroma is not formed. Extracts of garlic contain large amounts of certain tripeptides (glutathione) that elicit kokumi sensation.

Taste and aroma: Sharp, strong, kokumi. Garlic aroma (sulphur compounds).
Texture: Depends on the preparation.

Garum

The antique Roman fish sauce, garum, is produced by fermentation via the fish's own intestinal enzymes in the presence of large amounts of salt. The fermentation releases free amino acids that have umami taste. In recent years, a number of modern variants of garum have appeared on the European marked, often based on anchovies and sprat. Similar types of fermented sauces with great umami potential can be made using other proteinaceous raw materials, like insects, game and legumes. Garum has the same uses with vegetables as other fish sauces and can be used in dressings, sauces and marinades.

Taste and aroma: Umami, kokumi, salt.
Texture: Liquid, slightly viscous.

Gastrique

Gastrique is a viscous, sweet-sour-bitter and syrupy liquid cooked with caramelized sugar and vinegar. It can be used both as a colouring and flavouring agent with vegetables and in dressings and sauces. It can also be employed for glazing of vegetables.

Taste and aroma: Sour, sweet, and bitter.
Texture: Viscous and slightly sticky.

Ginger

Ginger root (*Zingiber officinale*) is used as a spice and flavouring agent to all sorts of food, not least vegetables. It is also used in marinades, sauces and juices. Ginger root contains a series of aromatic compounds such as gingerol, zingeron, zingiberen and shogaol. It is gingerol that is responsible for the sharp and burning taste sensation. Fresh ginger root can be salt, sweet or sour pickled. Pickled ginger root (*gari*) is commonly used with sushi and sashimi.

Taste and aroma: Sharp and burning. Lemon-like aroma.
Texture: Crisp. Woody when raw.

Goma-shio

Goma-shio is a Japanese-inspired spice mix made from ground, roasted sesame seeds (*goma*) together with sea salt (*shio*). *Goma-shio* can be sprinkled on vegetable dishes.

Taste and aroma: Salt. Nutty aroma with sulphuric aroma (furfurylthiol).
Texture: Crispy, oily.

Gremolata

Gremolata is an Italian-inspired spice mix based on chopped parsley with fresh lemon rind and garlic. Excellent to provide taste and aroma to cooked vegetables.

Taste and aroma: Sour. Garlic aroma. Etheric oils form parsley (e.g. myristicin).
Texture: Granulated, slightly moist.

Ham (dry and cured)

Cured ham is found in a variety of products both from ordinary pigs and black foot pigs (*pata negra*). *Pata negra* is particularly flavourful because the pigs feed on wild fruits like acorn that have large amounts of polyunsaturated fatty acids, rendering the fat flavourful and melting. Cured ham is dried and fermented, and in some cases also salted and smoked. During this process, glutamate and hence umami taste are formed. Only very small pieces of cured ham are needed to provide essential umami to vegetables and green dishes, in particular green salads.

Taste and aroma: Umami, sweet.
Texture: Depends on the cut. The fat is melting in the mouth.

Hoisin sauce

Hoisin sauce is a Chinese sauce typically produced by fermented soybeans, fennel, chili, garlic and possibly vinegar and sugar. Hoisin sauce can be used as a dip with vegetables, in marinades, and in vegetable wok dishes.

Taste and aroma: Umami, sour, sweet, hot. Garlic aroma.
Texture: Viscous and slightly sticky.

Katsuobushi

Katsuobushi is a bone-hard filet of bonito that has been five times over conserved by cooking, salting, drying, smoking and fermenting. Due to the applied method of fishing and the conditions of the preparation process, *katsuobushi* contains extraordinarily large amounts of inosinate, that enter synergistically in the umami taste. Ultrathin shaved flakes of *katsuobushi* are used when preparing *dashi*. Shaved *katsuobushi* can be used to sprinkle over cold and warm vegetable dishes and also used in dressings and sauces.

Taste and aroma: Umami, salt, bitter. Smoky aroma.
Texture: Dry. In shaped form, melts on the tongue.

Ketchup

Ketchup was originally a Chinese fish sauce (*koe-chiap*) that in the modern version no longer is based on fish, but basically a tomato paste to which fungi, anchovies, vinegar, walnuts, pickles and different spices are added. Many commercial brands also have large amounts of added sugar whereby all five basic tastes are represented. Ketchup is used as an all-purpose dip with vegetables as well as in dressings and sauces.

Taste and aroma: Umami; salt; sout; bitter; sweet.
Texture: Viscous and creamy.

Koji

Koji is a fermentation medium with a mould, *Aspergillus oryzae*, whose enzymes can break down starches into sugar (in particular glucose) and proteins into free amino acids and peptides. The sugars can subsequently be exploited by yeast that in turn can form a myriad of compounds, including alcohol and amino acids with umami taste. This kind of double fermentation is the basis for sake production. *Koji* can be produced on a mass of cooked soybeans, rice, barley or other cereals. This mass is then incubated by the mould. *Koji* can be applied to vegetables rendering them sweeter and having umami, thereby also suppressing possible bitter tastes (e.g. in cabbages). An easier way to apply *koji* is by means of so-called *shio-koji*, which is a medium based on malted rice and a high salt content. Under these conditions the mould is inactivated but its active enzymes remain, and it is only these enzymes that are needed to make vegetables more delectable by 'umamification'. A filtered product of *shio-koji* is called *ekitai shio-koji* that similar to *shio-koji* can also be used in dressings and marinades, e.g. for production of *tsukemono.*

Taste and aroma: Umami, salt. Yeasty aroma.
Texture: Viscous, and slightly granulated paste. *Ekitai shio-koji* is a yellow transparent liquid.

Lees

Lees are a sediment and waste product from brewing processes, e.g. from sake and beer. The lees consist of starch, sugars, free amino acids, in particular glutamate, as well as some alcohol. Hence lees have umami taste and is useful for marinating and conserving vegetables, e.g. as *tsukemono*. In particular, lees from sake production (*sake-kasu*) are excellent since they are not bitter in contrast to lees from beer production. Lees can enter marinades and dressings for vegetable dishes.

Taste and aroma: Umami, sweet, yeasty.
Texture: Granulated, creamy.

Marmite

Marmite is a trademark for a yeast product in the form of a sticky, dark and salty paste with a prominent umami taste. It contains significant amounts of vitamin B_6 and B_{12}. It is a British tradition to use Marmite as spread on bread and biscuits or to suspend in hot water as a nutritious and hearty beverage. Marmite can be used in sauces and dressings to impart umami to vegetable dishes.

Taste and aroma: Umami. Yeasty aroma.
Texture: Sticky and syrupy.

Mayonnaise

Mayonnaise is an emulsified sauce that in contrast to hollandaise and bearnaise is used cold. A classical mayonnaise is made of a mixture of vegetable oil

and lemon juice (or vinegar) and then emulsified by aid of egg yolk, mustard, and salt, pepper, and possibly other spices. The cooking water from chickpeas can also be used instead of egg yolk as a vegetarian emulsifier. The mayonnaise is made by first mixing lemon juice and egg yolk, and then slowly adding the oil while whipping, in the beginning just a drop of oil at a time. The mayonnaise will separate if oil is added too quickly, or there is too little water (from the juice or added water). In a good mayonnaise, the small oil droplets are so close that they induce a certain rigidity and an elastic mouthfeel. Aïoli is a variant of mayonnaise with garlic. Another variant is relish that is made of mayonnaise with chopped pickles. Mayonnaise can be used as a dip with vegetables or as a base for dressings and sauces.

Taste and aroma: Salt and sour. Strong from black pepper. Aroma from the added spices.
Texture: Creamy and mouthcoating.

Mirin

Mirin is a sweet rice wine with an alcohol content of about 14 per cent. Mirin is produced from cooked rice that is inoculated with *koji*. The *koji* turns the starches of the rice into sugars and the proteins into free amino acids with umami taste. Yeast is then added to ferment the sugars into alcohol. *Mirin* is not drunk but only used to add sweetness and umami to food, and it enters *ponzu* and *sanbaizu*. *Mirin* is used for steaming, glazing and caramelizing of vegetables. It can also be used in dressings and sauces.

Taste and aroma: Sweet, umami.
Texture: Liquid.

Miso

Miso is a fermented mass of soybeans and/or different cereals produced by the use of *koji*. Miso contains typically 14 per cent protein and large amounts of free amino acids, in particular, glutamat that elicits umami taste. The salt content varies from 5 per cent to 15 per cent. The longer the fermentation and storage period, the more powerful and darker the miso becomes and it is also saltier. *Shiro-miso* is sweet, white miso; *aka-miso* is red miso; *miso-zuke* are vegetables pickled in miso; miso soup is made from *dashi* to which is added miso. Miso is one of the most important components of the vegan Japanese temple cuisine, *shojin ryori.* Miso can be used in soups, as a dip, and in dressings, sauces and marinades together with vegetables.

Taste and aroma: Umami, salt. Yeasty aroma. *Shiro-miso* is sweet.
Texture: Creamy and granulated, depending on the type.

Mustard

Mustard is made from the seeds of the mustard plant. There are white/yellow (*Sinapis alba*), brown (*Brassica juncea*) and black mustard (*Brassica nigra*) seeds. The seeds are ground coarsely or finely with water, vinegar, salt, and in some

recipes with sugar. Certain proteins in the mustard oil emulsify the mixture rendering it a coherent viscous liquid or paste. When mashed, the mustard seeds release via an enzymatic action certain sharp and burning compounds called isothiocyanates. The more acidic mustard, the longer the burning sensation lasts. Dark mustard seeds give the strongest mustard. Mustard is used in dressings, sauces and marinades.

Taste and aroma: Sharp, burning, irritating, strong.
Texture: Creamy or granulated.

Panko

Panko are flaky and very dry Japanese breadcrumbs that are particularly suited for breading, e.g. frying vegetables. They are made from a special kind of bread that is baked by letting an electric current pass through the dough. The baked bread is very white and has no crust. When it is completely dry, the bread is shaved into fine flakes or a granulated mass. *Panko* has a particularly airy and porous structure that limits oil absorption, hence providing for a dry and very crisp structure of breaded and fried vegetables, e.g. Japanese *tempura*.

Taste and aroma: Sweet.
Texture: Dry and crispy.

Parmesan cheese

Parmesan cheese (Parmigiano-Reggiano) is a hard, granulated dry cheese. It is produced from a mixture of unpasteurized cow milk and skimmed milk. It has a rather low fat and salt content, compared to other hard and matured cheeses, and is matured for at least two years. Parmesan cheese is one of the processed food products that contains the largest amount of free glutamate, only dwarfed by some fish sauces. The umami power of parmesan cheese is almost unsurpassed when adding umami to vegetables and reducing their perceived bitterness. It can be shaved on green salads and be added to dressings and sauces.

Taste and aroma: Umami, salt, bitter.
Texture: Hard, dry and granulated.

Pepper

There are a number of species of genuine pepper from the *Piper* genus, e.g. black pepper (*Piper nigrum*) and long pepper (*Piper longum*). Black pepper is dried whole pepper berries. The same pepper berries turn out white if the fresh berries are soaked in water and the fruit flesh is removed. Green pepper (Madagascar pepper) is unmatured pepper berries. There are also a number of 'not-peppers' which we call pepper, but they do not belong to the *Piper* genus. For example, rosa pepper (*Schinus molle*), allspice (*Pimenta dioica*), sansho (*Zanthoxylum piperitum*), grains of paradise (*Aframomum melegueta*) and Sichuan pepper (*Zanthoxylum simulans*). All peppers and 'not-peppers' lead to different degrees of hot and burning feeling (chemesthetic or

trigeminal sensation) but are distinctly different in their aromas. Black pepper becomes hot due to piperin and chavicin, and white pepper has more of these compounds than black pepper. Kampot pepper is a variant of black pepper that is very aromatic and well known in the Cambodian cuisine. Pepper is universally used in almost all green and vegetable dishes.

Taste and aroma: Strong, hot, burning. A range of different aromas.
Texture: Depending on use.

Pesto

Pesto is a purée, paste or sauce that is partly emulsified by oil. Classical Italian pesto is based on grounded fresh basil, garlic and pine nuts mixed in olive oil, possibly with some parmesan cheese. Parsley and seaweeds can also be used in a pesto. Pesto can be used as a dip with raw vegetables, spread on bread, and as a condiment with vegetable dishes.

Taste and aroma: Salt, sharp, sour. Aroma from basil and parsley.
Texture: Soft and creamy. Granulated.

Pickles

Pickles are made from vegetables with a certain amount of salt, vinegar and possibly some sugar and spices, such as chili and dill. Pickles are a green dish in themselves but can also be used to give taste and texture to other green dishes. Pickles are commonly made with cucumber and, in certain preparations, the vegetables have been subject to lactic fermentation. Cornichons are small pickled cucumbers spiced with tarragon. Chopped pickles are a component of relishes. *Tsukemono* are a large family of Japanese pickles.

Taste and aroma: Sour, salt. Possibly sweet and spicy.
Texture: Crisp and crunchy.

Potato cooking water

The water from cooking potatoes is an overlooked source of umami, in particular when made from old potatoes and potatoes with peel. The potato cooking water contains fair amounts of free glutamate and hence elicits umami. It can therefore be used to steam and sauté vegetables or enter sauces and dressings. Different potatoes lead to potato water with different flavours.

Taste and aroma: Umami, sweet.
Texture: Liquid.

Ponzu

Acidic marinades adjusted with sweetness and umami are a good match with vegetables. The Japanese cuisine is world famous for such marinades or condiments and they all contain flavourful rice vinegar (*su*). The two most famous

Japanese condiments are *ponzu* and *sanbaizu*. *Ponzu* is made from *dashi*, *yuzu* juice, rice vinegar and *mirin*. *Sanbaizu* is basically *ponzu* without *yuzu*. *Ponzu* is a universal condiment for all sorts of vegetable dishes, in sauces and in dressings.

Taste and aroma: Umami, sour, salt. Citrus notes and aromas from *yuzu*.
Texture: Liquid.

Roasted nuts and seeds

Roasted seeds of pumpkin, sunflower, hemp and sesame, as well as nuts like cashew or hazelnuts all have flavourful etheric oils and they become crisp when roasted on a pan, possibly in a bit of neutral oil. Adding some soy sauce or *ponzu* before finishing the roasting yields a potent umami taste. Extra aroma can be provided by adding a bit of tamarind sauce. Hence the resulting seeds and nuts are good to add both texture and umami to vegetable dishes.

Taste and aroma: Aromatic oils. Umami.
Texture: Crunchy and crisp.

Sake

Sake is rice wine produced by fermentation of cooked white rice that has undergone a double fermentation, first with *koji* and then by yeast. Sake therefore contains high levels of sweet and umami-tasting free amino acids. Cooking sake is a lower grade of sake only used for cooking and not drinking. Sake can add umami when steaming vegetables and in sauces and dressings. Sake lees (*sake-kasu*) have ample amounts of dead yeast cells and amino acids and make a very potent umami source that is excellent as a pickling bed for vegetables or in sauces and dressings.

Taste and aroma: Sweet, umami. Alcoholic.
Texture: Liquid.

Salsa verde

Salsa verde is a green and spice sauce well-known from the Mexican cuisine. It is traditionally made from tomatillo (*Physalis* spp.) and chili by cooking and blending the ingredients, and in some cases, adding some oil. Versions of *salsa verde* contain parsley, onion, garlic, anchovies and capers, often enriched with mustard. Anchovies and capers add umami, and garlic provides kokumi. *Salsa verde* can be used as a dip with vegetables and in sauces, dressings and soups.

Taste and aroma: Sweet and hot. Possible umami and kokumi.
Texture: Depending of preparation method.

Sansho

Sansho is a Japanese type of pepper (*Zanthoxylum piperitum*) that is not a genuine pepper. Its taste and aroma are similar to the Chinese Sichuan pepper.

Sansho can be used as an aromatic condiment to green dishes. The aroma is similar to mint and basil with notes of liquorice. It is used both dried and ground as well as simmered in soy sauce. The hot taste sensation of *sansho* is more subtle than that of black pepper and chili. *Sansho* is a component of the spice mix *shichimi*. *Sansho* is commonly used in dressings and marinades.

Taste and aroma: Hot, burning. Aromatic.
Texture: Depends on application.

Shellfish powder

Shellfish powder can be made of dried shrimp, mussels and littoral crab. Mussel powder can be made from reduced boiling water from cooking blue mussels. Shrimp heads can be smoked, dried and turned into a powder. Shellfish powders can be used as a kind of soup powder. These powders can be used with the cooking water from potatoes to produce a kind of *dashi* with good umami synergy. Both powder and *dashi* can be applied to add umami when steaming vegetables or in sauces, soups and dressings.

Taste and aroma: Umami, salt. Marine aroma, possibly smoked.
Texture: Dry.

Shichimi

Shichimi is a Japanese seven-spice mixture that typically contains *sansho*, red chili, dried ginger, *ao-nori* (a green seaweed species), *yuzu* peel and hemp seeds. There are different local variations, but all contain seven different species. *Shichimi* can be used as a general spice and in sauces, marinades and dressings to go with vegetables.

Taste and aroma: Umami, sour. Strong and sharp. Aromatic oils.
Texture: Dry and possibly crunchy.

Soy sauce

Soy sauce is made by fermenting soybeans, wheat and possibly other cereals like rice and barley, each leading to their characteristic flavour of the end product. Wheat and rice lead to a sweeter soy sauce. The salt content is high, 14–18 per cent. The fermentation leads to the production of large amounts of free amino acids and hence umami. Because the process and the subsequent maturing period is very lengthy, Maillard compounds are formed with their characteristic and rich flavour profile. For flavouring vegetables, the Japanese soy sauce is more elegant than some heavy and viscous black Chinese soy sauces. Soy sauce is a universal means to flavour vegetables and green dishes, e.g. via sauces and marinades.

Taste and aroma: Umami, salt. Flavour from Maillard compounds.
Texture: Liquid.

'Seaweed liquorice'

Brown seaweeds like sugar kelp (*Saccharina latissima*), sea tangle (*Laminaria digitata*), and best *konbu* (*Saccharina japonica*) can be prepared with a texture similar to soft liquorice with a potent umami taste. The preparation involves simmering the seaweed in soy sauce, sweet mirin, and possibly a bit of shiitake powder. When based on *konbu*, the result is called *konbu-tsukudani*. The 'seaweed liquorice' can be used on both cold and warm vegetable dishes.

Taste and aroma: Umami and salt.
Texture: Similar to soft liquorice.

Seaweed powder/salt

Seaweeds can be uses as a salt replacement and flavour enhancer in the form of a dry powder or granulate. Brown, red and green seaweeds contribute different flavours and saltiness. Seaweed powder/salt can be used to sprinkle on vegetable dishes, and be an ingredient in bread, dressings, sauces and soups.

Taste and aroma: Umami, salt, bitter. Some species have sulphur, iodine and bromine notes.
Texture: Dry and granulated.

Tahini

Tahini is a paste made from ground sesame seeds. Sesame seeds are rich in oils, and since they also are rich in antioxidants, tahini keeps for a long time without going rancid. Because of a certain content of glutamate, sesame seeds and tahini can contribute some umami to dressings and vegetables. In order to enhance the umami taste, tahini can favourably be mixed with Worcestershire sauce or miso.

Taste and aroma: Umami. Nutty aroma like roasted coffee (furfurylthiol).
Texture: Oily and creamy.

Tamarind sauce

Tamarind is a sour, sweet, sticky and concentrated mass derived from the fruits of a tropical tree (*Tamarindus indica*) and is an ingredient in Worcestershire sauce and often used in Indian curries and chutney. It can be used to flavour sauces and dressings for vegetable dishes.

Taste aroma: Sour and sweet. Roasted and aromatic.
Texture: Viscous and sticky.

Tomato (sundried, paste)

The most concentrated tomato flavour is found in dry, sun-ripe tomatoes and tomato purée. Although technically a fruit, the tomato is considered a

vegetable. Because the ripe tomato is rich in both free glutamate and a free nucleotide (adenylate) it exhibits perfect umami synergy. The tomato and preparations of tomatoes are therefore a universal cure to impart umami to all green dishes, in particular salads. Tomato paste is also used in dressings, sauces and marinades.

Taste and aroma: Umami, sweet.
Texture: Chewy and firm. Granulated and creamy in pastes and purées.

Truffles

When black truffles are mature and ready to disperse their spores, they emanate a potent musk aroma. Their taste is earthy and a little sulphuric (from dimethyl sulphate) with notes of sweet fruits. When heated they release their aroma and should hence be added to warm dishes just before serving. Summer truffles (*Tuber melanosporum*) have a milder aroma and taste than winter truffles (*Tuber aestivum*) that have a deep and strong flavour. White truffles (*Tuber magnatum*) have a fuller flavour than the black ones and their taste is a little sharper and bitter but at the same time more subtle and aromatic, which makes them more sought after and more expensive. Truffles have many uses with vegetables and go particularly well with white asparagus and potatoes.

Taste and aroma: Umami. Musk. Earthy, sweet and sulphuric (black truffles) and sharp and bitter (white truffles).
Texture: Firm and slightly crunchy.

Tsukemono

Tsukemono is a form for preserved and pickled vegetables prepared according to ancient Japanese techniques involving drying, marinating (salting, pickling) and fermenting. The various types of preparation use salt, vinegar, sugar, alcohol, *dashi* and a range of spices. *Tsukemono* can be used as a vegetable snack, condiment or added into salads and relish.

Taste and aroma: Sour, salt, sweet, umami. Possibly fermented aroma.
Texture: Crunchy.

Verjus

Verjus means 'green sauce' and is made by cooking and maturing grapes to a syrup-like juice. Verjus can in some cases replace vinegar and lemon juice in green dishes. Balsamic vinegar can in principle be seen as a long-lasting fermentation and maturing of verjus. Verjus is used in sauces and for deglazing.

Taste and aroma: Sour, sweet, tart. Green aroma.
Texture: Viscous.

Vinaigrette

Vinaigrette is a cold, non-thickened sauce or dressing that is a mixture of oil whipped into vinegar to which salt, pepper and possibly a variety of spices are added. Variations, depending on the end use, include mustard, lemon juice or tomato purée. In its simplest form, vinaigrette is not emulsified, although mustard can facilitate emulsification, and therefore it has to be shaked vigorously before added as a dressing to green dishes.

Taste and aroma: Salt and sour. Possibly hot and spicy.
Texture: Liquid, possibly separated into an oily and aqueous phase.

Vincotto

Originating from Italy, vincotto means 'cooked wine'. The taste is similar to balsamic vinegar but is much less sour. It is excellent in salad dressings and with cooked vegetables.

Taste and aroma: Sweet, caramel notes.
Texture: Viscous, sometimes like a paste.

Vinegar

Vinegar is made from yeasted wine or yeasted fruit juice, such as cider, by acetic fermentation where alcohol is turned into acetic acid along with a cascade of aroma compounds depending on the starting point. Vinegar is the most important local source of sour taste in food cultures that cannot grow citrus trees. Matured types of vinegar include balsamic vinegar. Japanese rice vinegar (*su*) has a softer and more delicate taste than most vinegars produces from fruit juices. Vinegar is used in marinades, dressings and for conservation of vegetables.

Taste and aroma: Sour, different aromas.
Texture: Liquid.

Worcestershire sauce

Worcestershire sauce was originally a fermented anchovy sauce and hence related to the classic Roman garum. It contains anchovies, vinegar, molasses, salt, sugar, tamarind, onions, garlic and possible other flavouring agents like soy sauce, cloves, lemons, pickles and pepper. Worcestershire sauce can be used in dressings and sauces.

Taste and aroma: Umami, salt, sweet, sour. Aroma from the applied spices.
Texture: Dark and viscous.

Yeast and yeast flakes

Yeast flakes (nutritional yeast) are small flakes of dried and inactivated baker's yeast (*Saccharomyces cerevisiae*) cultivated on a substrate of molasses from

sugar beets or sugar cane. The yeast cells and their enzymes are deactivated by heating, after which the yeast is washed and dried. Yeast flakes are different from yeast extract that is darker and has a much stronger flavour. Yeast flakes have a fair amount of free glutamate but not as much as yeast extract. They are a good source of vitamin B and important amino acids and hence often are recommended as a nutritional supplement. Yeast flakes can be sprinkled on vegetable dishes. When dispersed in cold water or sake, yeast flakes make a good and creamy dressing with umami taste, possibly with addition of a bit of vinegar and some spices or seaweed granulates.

Taste and aroma: Umami. Nutty aroma, with notes like parmesan cheese and miso.
Texture: Dry. Creamy when mixed with water.

Yukari (salted red shiso, furikake)

The Japanese cuisine uses a range of dried spice mixes and condiments, so-called *furikake* that can be sprinkled on cooked rice and vegetable dishes in order to add umami and crispness. *Furikake* contains typically roasted seaweed, sesame seeds, chili, *yuzu* rind and dried fish flakes. A particular form of *furikake* is *yukari* that is salted, dried and granulated leaves of red *shiso* (*Perilla frutescens*). Since perilla contains certain antifungal compounds, *shiso* is also used for conservation of vegetables and fruits (e.g. pickled plums, *umeboshi*).

Taste and aroma: Salt. *Perilla*-aroma.
Texture: Dry and granulated.

Yuzu

Yuzu is a small Japanese lemon (*Citrus junus*) with a more complex and aromatic flavour than lemon and lime. The best taste and aroma are found in the rind, whereas the juice is somewhat bitter. *Yozu* juice and dried rind are used in *ponzu* and the *shichimi* spice mixture, respectively. *Yuzu* is used in dressings, marinades and sauces to be used with vegetable dishes.

Taste and aroma: Sour, complex aroma.
Texture: Depends on preparation.

Za'atar

Za'atar is a spice mixture from the Middle East and is well-known in Palestine and on the Arabic Peninsula. The mixture is commonly used with greens and vegetables. It contains sesame and coriander seeds, sumac, oregano, sea salt, thyme and possibly chili. Used in dressings and with freshly baked bread.

Taste and aroma: Salt, sour, nutty. Aromas from the spices.
Texture: Dry, granulated.

Oyster sauce

A genuine oyster sauce is prepared by slowly reducing the water in which oysters have been cooked. The result is a caramelized, brown liquid to which salt is added. However, some commercial oyster sauces are made by oyster extract that is thickened by corn starch, coloured by caramel and with added salt and MSG. It is used in dressings for vegetables and beans.

Taste and aroma: Umami, salt.
Texture: Liquid and slightly viscous.

CASE STUDY 1: LITTLE APPRECIATED VEGETABLES NEED UMAMI

For various reasons some vegetables have lower status than others and are consequently little appreciated. Members of the cabbage genus (*Brassica*), such as broccoli, broccolini, cone cabbage and Chinese cabbage, and the radish genus (*Raphanus*), such as Chinese radish (*daikon*), are generally considered challenging because of the omnipresent sulphuric odour and the intrinsic bitterness so characteristic of the crucifer family (Brassicaceae). A common trait for many members of this family, in particular cabbages and radishes, is a potent cabbage smell that is caused by certain sulphur compounds, the characteristic aroma compound being 5-methylthiopentanitril. They are also often bitter due to polyphenols and they elicit an irritating mouthfeel (chemesthesis) due to enzymatic degradation of glucosinolates into isothiocyanates (Belitz, Grosch, and Schierberle 2004; McGee 2004).

Moreover, cabbage is in some food cultures considered as a bulk stable associated with poor people's diet, and the large volume of a sturdy production and the low prices do not help to hype cabbage. For the same reason, potatoes have since the Second World War fallen out of favour, although the potato is a very nutritious vegetable which allegedly was responsible for doubling the European population from 1700–1900 (Zuckermann 1998). In addition, potatoes have been belaboured for their large starchy and caloric content and it has somewhat been overlooked that they contribute umami, vitamin B_6 and C, iron, potassium and zinc, and that their skin contains plenty of dietary fibres and antioxidants. In fact, it is possible to survive on a diet of just potatoes and dairy products.

Below is shown how to use elements of the 'taste rack' of condiments to design and prepare simple and delicious dishes of cabbage and radish. Furthermore, the potato is highlighted as both a delectable vegetable and its potential for 'umamifying' other vegetables.

Broccoli

Broccoli (*Brassica oleracea* convar. *botrytis* var. *italica*) is often considered to be a 'hate vegetable' because of its intrinsic bitterness. It is both the unmatured flower body as well as the stems that are eaten. It has a typical cabbage smell and taste, some of which disappears upon cooking. The raw texture is hard and crunchy. It is excellent for steaming and deep frying, as well as fermentation and treatment with *shio-koji* that imparts sweetness, umami and dampens the bitterness. Figure 1 shows a preparation of deep-fried broccoli that is extremely crunchy. The missing umami is supplied by a miso-mayo.

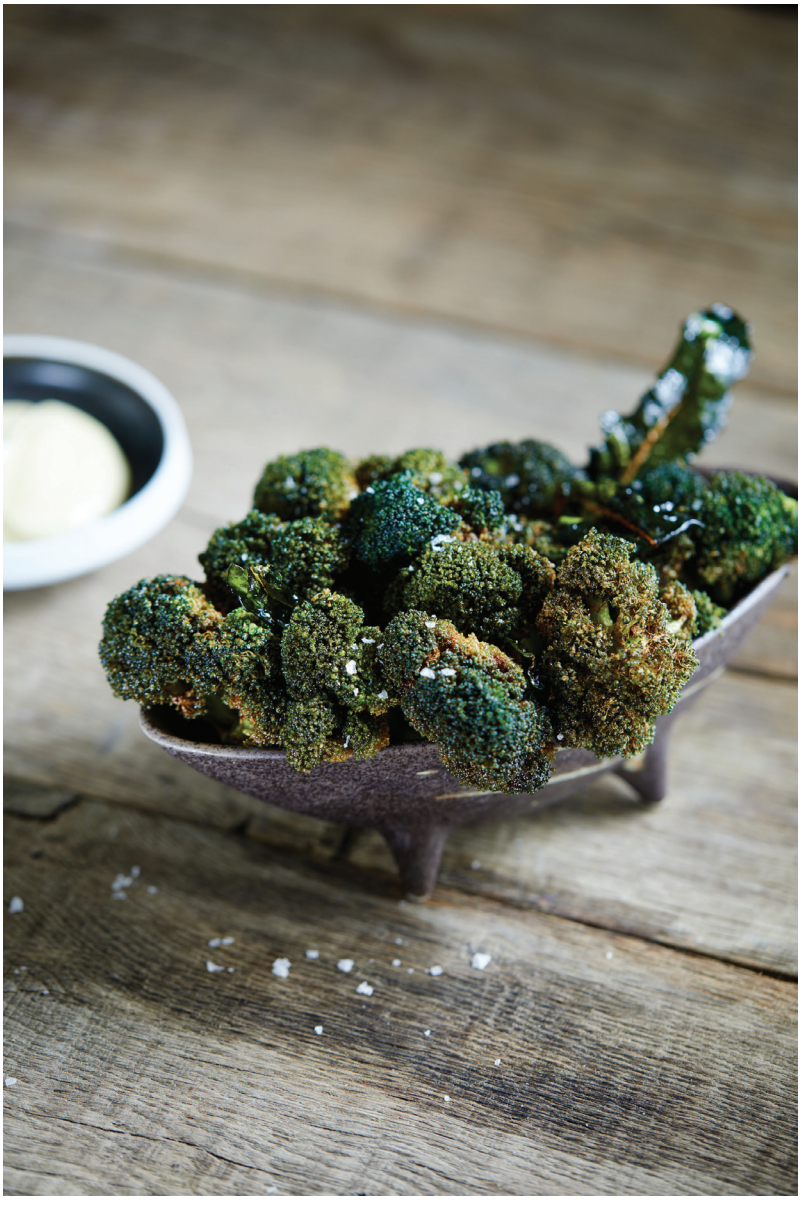

Figure 1: Deep fried broccoli with miso-mayo.

Broccolini

Broccolini is a cross (*Brassica oleracea* × *alboglabra*) between broccoli and Chinese kale. The flower bodies are smaller than on broccoli. Both the unmatured flower bodies and the stems are eaten. As broccoli, broccolini is bitter and has a pungent cabbage smell and taste. The stems are usually a little more tender and less woody. Broccolini can be prepared in the same way as broccoli. Figure 2 shows a presentation of raw broccolini prepared in *shio-koji* that imparts sweetness, umami, and leads to a surprising lowering of the bitterness.

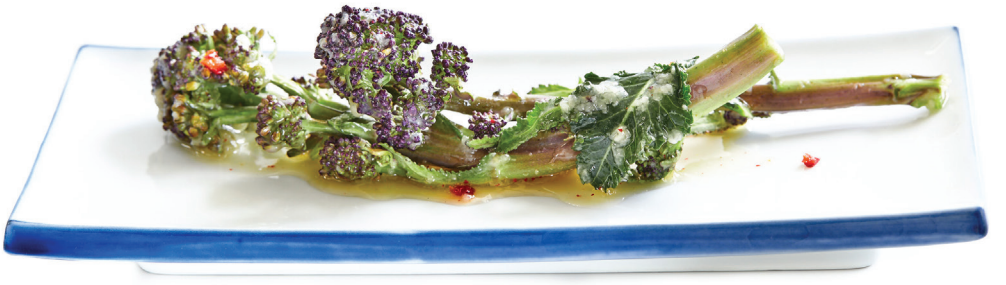

Figure 2: Broccolini in shio-koji *with chili and fish sauce.*

Additional umami is provided by adding fish sauce to the marinade, and a bit of chili engages the trigeminal taste sensation. Broccoli and broccolini haters will be amazed by the deliciousness of this preparation.

Chinese radish

Chinese radish (*Raphanus sativus* var. *longipinnatus/acanthiformis*) is also known by its Japanese name *daikon*. It has a sharp and peppery taste. It is rather crisp when fresh and raw and becomes succulent when cooked. It is a shamelessly overlooked vegetable in Western cuisine. It can be eaten raw (often julienned), simmered, steamed, pickled, dried and marinated. It is one of the most outstanding vegetables for preparing Japanese-style *tsukemono* (Mouritsen 2018), a technique that renders the radish extremely crunchy, e.g. in the form of dried and fermented *takuan-zuke*. Figure 3 shows a preparation of Chinese radish where slices of it has been simmered in *dashi* and drizzled with soy sauce. In this form, the *daikon* is extremely succulent and still firm, and its sharp taste and aroma has turned into mild notes, and the umami from the *dashi* and soy sauce has taken over.

Chinese cabbage

Chinese cabbage (*Brassica rapa* ssp. *pekinensis*) has got a somewhat bad reputation because it often appears in salads without much taste. Its cabbage flavour is rather weak and mild, and when it is fresh and raw, it is juicy and crisp. It is often used in wok dishes and fermented in *kimchi*. In *kimchi*, the Chinese cabbage is subject to lactic fermentation that imparts both acidity and some umami flavour to the otherwise taste-neutral cabbage. Traditional kimchi also uses fermented shrimp paste that is rich in glutamate. In order to stimulate the fermentation, the cabbage is first rubbed with salt. Figure 4 shows a whole Chinese cabbage that has undergone lactic fermentation and was drizzled with a chili dressing.

Kohlrabi

Kohlrabi (*Brassica oleracea* convar. *caulorapa* var. *gongylodes*) must not be mistaken for swede (Swedish turnip) (*Brassica napus* ssp. *rapifera*). Kohlrabi has a typical cabbage flavour, and small and young specimens can be eaten

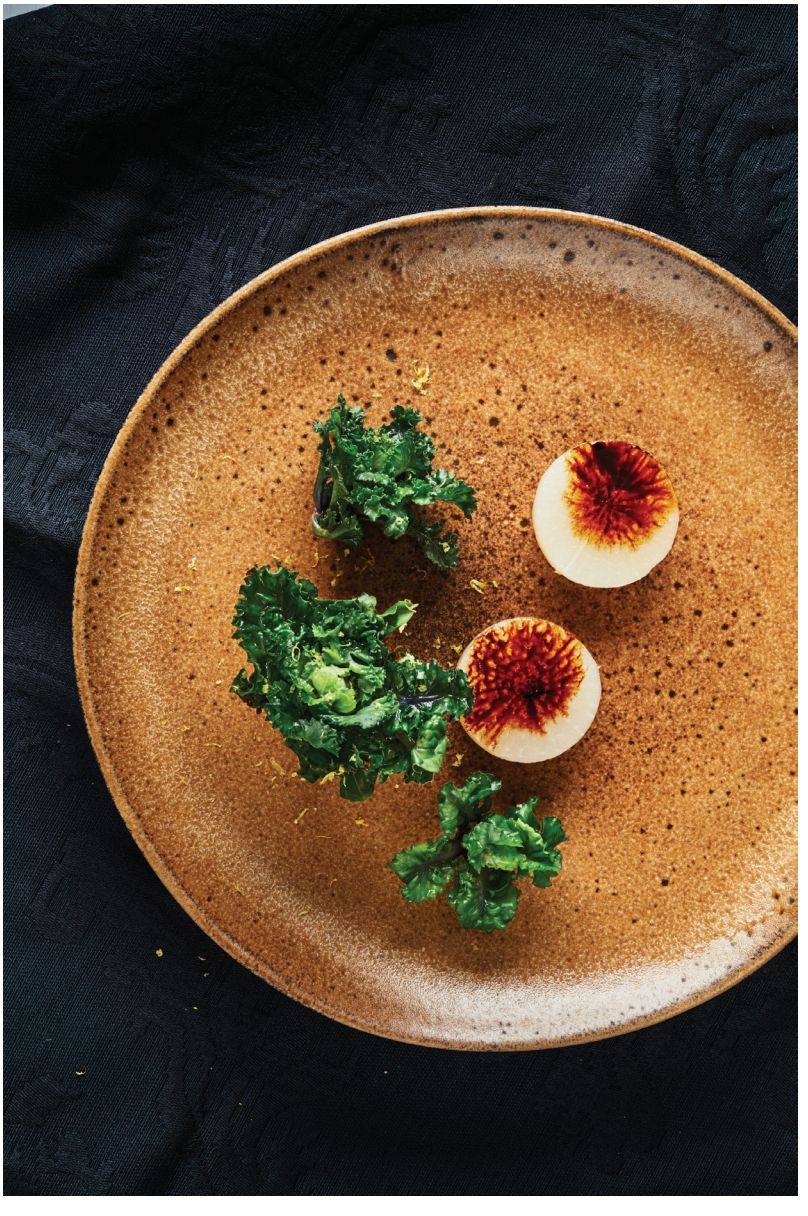

*Figure 3: Chinese radish (*daikon*) simmered in dashi, drizzled with soy sauce, and served together with flower sprout (kalettes), a cross between kale and Brussels sprouts.*

raw where it is very crisp and firm. Older specimens can be somewhat woody. It is used in salads, as coleslaw, and as *tsukemono*, where it becomes extremely crunchy. When prepared as *tsukemono*, the kohlrabi is first dried and then marinated in a liquid based on *dashi* that is often enriched with umami taste from *konbu*-seaweed (*Saccharina japonica*). An example of kohlrabi *tsukemono* is shown in Figure 5.

Figure 4: Lacto-fermented Chinese cabbage with a chili dressing.

Potato

Common potato (*Solanum tuberosum*) belongs to the nightshade family (Solanaceae), and it develops large underground starchy tubers. Its taste is mild with a light bitterness and earthy notes (caused by the compound pyrazine). Young boiled potatoes that are the unmatured tubers have a sweet taste and a compact and humid consistency. Old mature tubers have a more intense taste, which is caused by a slowly working enzyme that break down the lipids

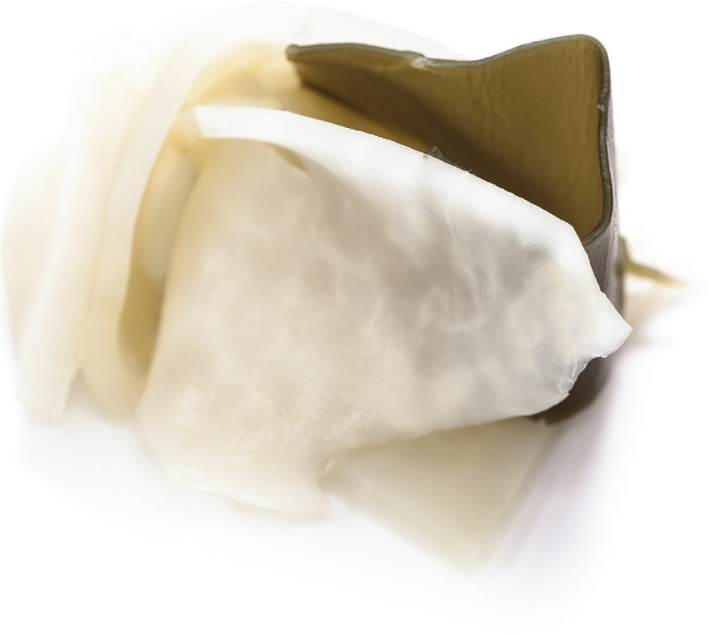

Figure 5: Tsukemono *made from kohlrabi that has been dried and then marinated in da*shi. Konbu-*seaweed* (Saccharina japonica) *adds further umami taste.*

in the cell membranes and leads to fruity and floral notes. Boiled potatoes, in particular unpeeled old ones, contain large amounts of free glutamate that elicit umami taste. Some of this taste seeps out into the potato cooking water, rendering this water a fine umami-rich medium for making sauces or for steaming vegetables.

Potatoes are commonly divided into three categories: mealy, firm and waxy. Mealy potatoes have a large starch content and are preferred as baked potatoes, mashed potatoes and potato soup. Firm potatoes have less starch and are excellent for peeling before or after being cooked, while still remaining somewhat firm. Waxy potatoes have the lowest amounts of starch and remain very firm after cooking. They are therefore preferred for potato salad and for roasting and braising. When waxy potatoes are pureed, they become somewhat rubbery and less capable of accepting grease.

The potato is an extremely versatile vegetable in the kitchen. It may be boiled, roasted, steamed, sautéed, mashed, fried, dried and sugar browned, and can be used in all sorts of cold and warm dishes with different tastes and textures. Figure 6 shows a simple serving of purple Congo potato and common white potatoes that are boiled in water with *konbu*-seaweed (*Saccharina japonica*) to enhance the umami taste. The umami-rich potato water is mounted

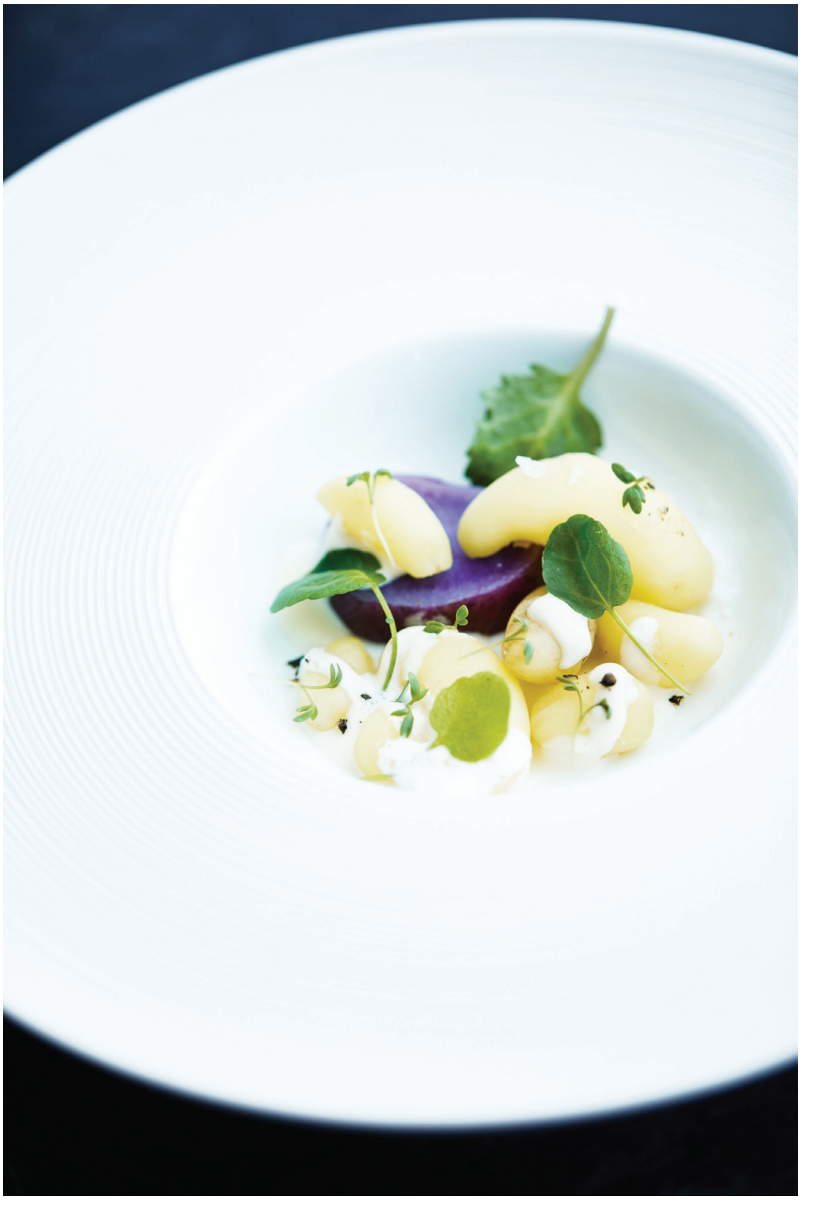

Figure 6: Different types of boiled and pealed potatoes with fresh goat cheese and a lot of cress.

with fresh goat cheese into a creamy sauce. Fresh cress adds some sharpness and bitterness to the dish.

CASE STUDY 2: VEGETABLES IN NEED OF CRUNCH

Some vegetables in raw form or as prepared, e.g. cooked, appear to some eaters as uninteresting because of a possibly soft, mealy, mushy or soggy texture. In prepared dishes, such vegetables need some texture contrast to appeal to

Figure 7: Overripe tomatoes with umami and crunchy pumpkin seeds, garlic and croutons.

the eater, and it is often a matter of adding ingredients or condiments which furnish a crunchy or crispy feel that also stimulates the auditory sense. Below, an example is given how to impart a crunchy mouthfeel and extra umami and kokumi to an already umami-rich dish of soft tomatoes. In addition, a cone cabbage dish that needs both umami and crunch is presented.

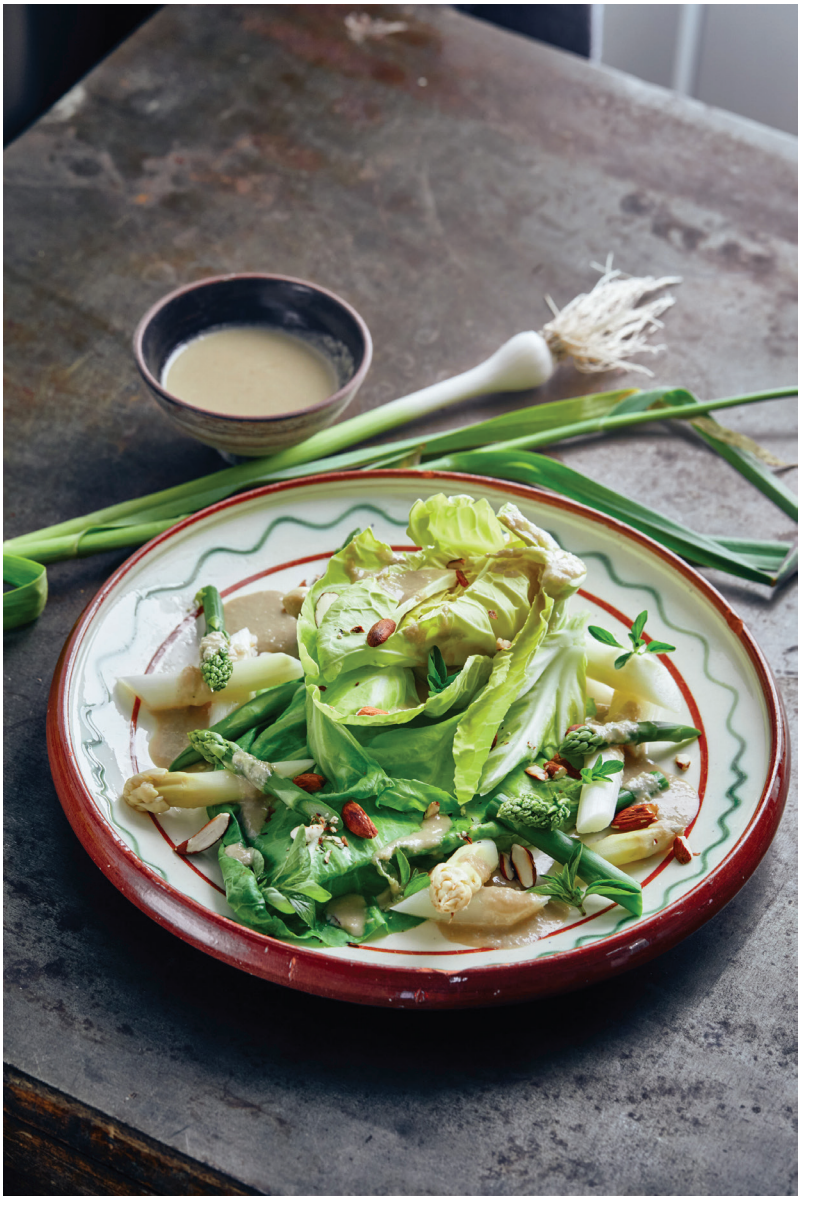

Figure 8: Cone cabbage, asparagus, anchovy sauce, and baked, salty almonds.

Tomato

Tomato (*Solanum lycopersicum*) belongs to the nightshade family (Solanaceae) and is actually a fruit in the botanical sense. It is among the most used vegetables in food cultures across the world. The reason for its wide use is likely due to the fact that when sun-ripened it is rich in two substances, free glutamate and free adenylate, that provide for umami taste synergy (Mouritsen

and Styrbæk 2014), in particular in the pulp (Oruna-Concha et al. 2007). The aroma is due to a range of volatile compounds, particularly hexanal, beta-ionon, beta-damascenon, 1-penten-3-one, and 3-methylbutanal. Upon heating, certain sulphur compounds are released. The texture is firm in the skin, and juicy and gooey inside. Upon heating, the tomato becomes soft and juicy. It is used in all sort of dishes, even desserts, and it can be eaten raw, dried, puréed, pickled, baked and sautéed.

The dish presented in Figure 7 is made from overripe tomatoes of different colours, along with onion, spring onion, green peppercorn, as well as various herbs and spices. The somewhat soggy tomatoes receive a texture contrast by being accompanied by roasted croutons, roasted garlic and crunchy pumpkin seeds fried in soy sauce. The marinade contains fish sauce and rice vinegar contributing umami taste. The garlic imparts a kokumi sensation along with the fish sauce. In this pure vegetable dish, the tomatoes take on the role of the 'meat'.

Cone cabbage

Cone cabbage or pointed cabbage (*Brassica oleracea* convar. *capitata* var. *conica*) that is found in both a green and purple variety is excellent raw in salads, prepared with *shio-koji* that imparts sweetness and umami, and is also commonly used in soups, as marinated, fermented, braised, baked and grilled. In Figure 8, a dish with lightly cooked cone cabbage, white and green asparagus, and an umami-rich condiment in the form of an anchovy sauce (*bagna càuda)* is presented. Crunchiness is supplied by baked, salted almonds.

CONCLUDING REMARKS

In the present article, the need for 'umamification' in order to make vegetables more delectable has been pointed out. Moreover, condiments can add interesting texture elements to green dishes in terms of crunchiness and crispness which are desirable for exposing texture contrasts. The extensive lists of condiments provided in the present article can be used to compose and design vegetable dishes that should be appealing to the palate of many people, including children and young people, thereby contributing to altered eating behaviours towards a green transition. To further facilitate this transition, there is a need for a broad dissemination of scientific knowledge about taste and taste preferences coupled with gastronomic innovation (Sørensen and Mouritsen 2019).

In summary, a lacto-ovo-vegetarian or flexitarian approach, using animal sources as a means of seasoning, is advocated as the most sensible and realistic way of eating sustainably in order to meet the EAT-Lancet Commission's recommendations (Willett et al. 2019) since rather small amounts of umami-rich foodstuffs from animals can make large volumes of green food delicious for a large population on a daily basis.

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