A FIELD GUIDE TO FERMENTATION

noma

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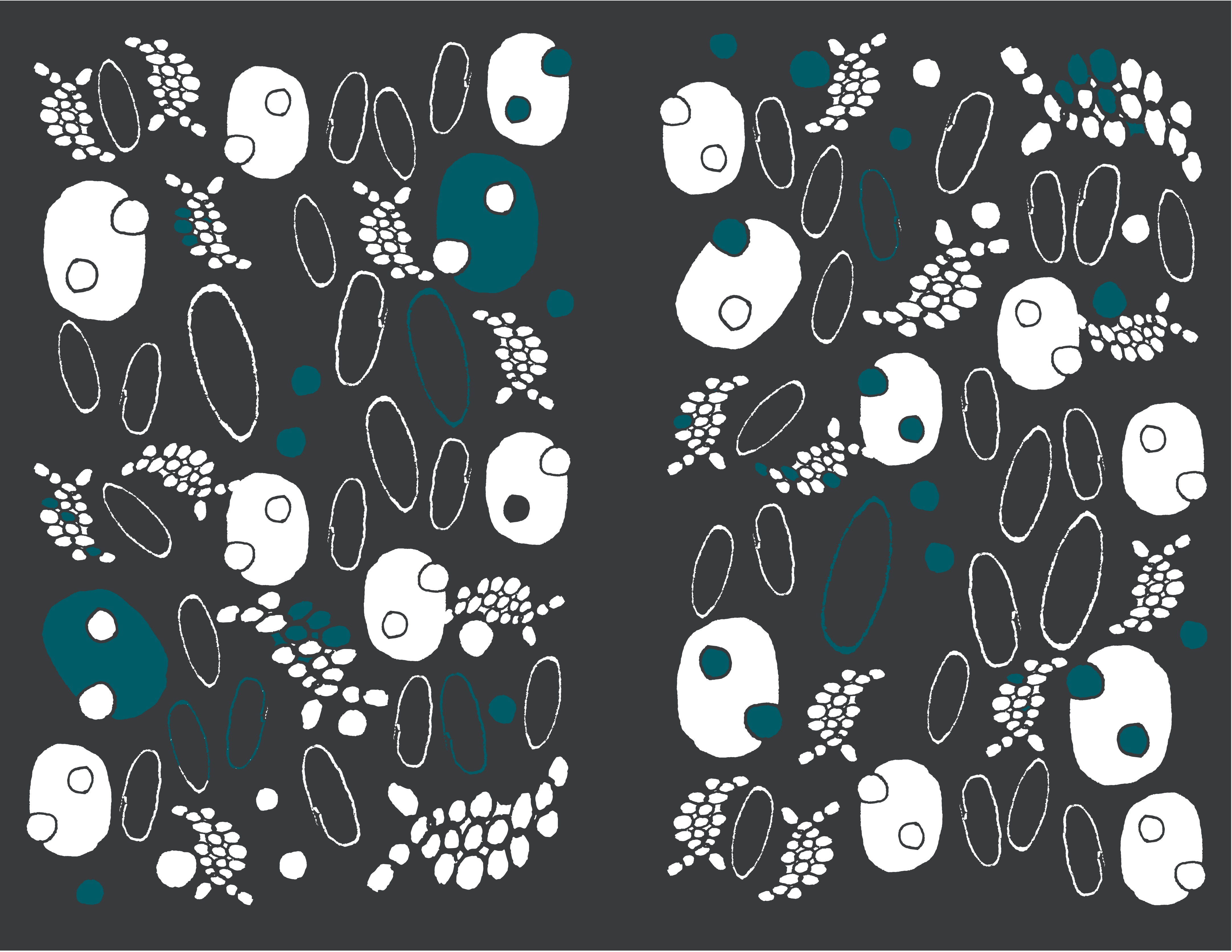
by Arielle Johnson and Lars Williams



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This book belongs to

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A field guide to fermentation

Written by Arielle Johnson and Lars Williams
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A Field Guide to Fermentation

What is in this book and how do I use it?

Each section of this book starts with the most basic practical information to do a fermentation for a noma recipe successfully. So if you only need to know exactly what to add to pumpkin juice to make pumpkin vinegar, or what the correct proportions of ingredients for a hazelnut miso are, that information comes first.

If you want to understand why you need to add each ingredient, or what role each step plays in creating the final product, this information follows each basic recipe, in increasing depth and complexity. Besides learning some cool stuff, such as the fundamental reasons for specific salinity, temperature, alcohol, or humidity, you can also use this deeper background information to develop new fermentations, or figure out what processes are likely to work well with different ingredients.

Chapter One

What is fermentation and why do we do it?

Fermentation is one of the many tools we use for preparing ingredients for the menu at noma. You might be most familiar with fermentation as the process that creates alcohol in wine and beer, or that causes bread dough to rise, or that makes kimchi or sauerkraut sour.

At its most basic, fermentation is the transformation of food by various microorganisms (bacteria, molds, and yeasts and fungi) and the enzymes they produce.[1] It is essential for the production of a wide range of foods and beverages, each with a distinct and varied flavor profile. Kimchi, wine, bread dough, vinegar, and soy sauce, while all tasting different, each owe their origin to the action of microorganisms.

Fermenting towards end-products as diverse as wine and kimchi, or squid garum and creme fraiche, is a matter of starting with different ingredients, and working with different microbes. The microbes—across human cultures generally, and at noma in particular—that we use for fermentation are yeasts and molds (both types of fungi) and acetic and lactic bacteria.

Why would you want to transform food with microbes in the first place? We do so simply because it's delicious. Throughout history, fermentation has been used for several different purposes. It can preserve perishable foods—making sauerkraut from cabbage extends its usable life, for example. Fermentation can also make foods easier or safer to eat, removing cyanide from cassava and the historically indigestible sugar lactose from dairy products. Other microbes create intoxicating substances such as alcohol. Finally, fermentation is often used for flavor—the purpose of camembert or sauternes is less about nutrition than deliciousness.

At noma, we ferment primarily for flavor. Rather than aiming for shelf-stability or specific health properties, the processes we use and the ways we use them are directed by the flavors they produce. This enables us to better utilize highly-flavored and short-seasoned ingredients. We can develop complex and interesting flavors in commodity and waste products, like dried yellow peas and squid trim. We can also create flavor profiles, like sourness and umami, that are not widely-occurring in Nordic products. Rather than attempting an exhaustive coverage of fermentation in all its possible forms, or even every single product fermented at noma, this book is rather an illustration of functional fermenting for flavor.

1 Per Sandor Katz, Godfather of the modern fermentation revival and MAD Symposium speaker in 2013

It takes some know-how to transform raw ingredients and microbes from start to finish, and to cultivate the kinds of flavors we want to work with instead of swampy, boozy, moldy, chemical-like, or rotten ones. One part of this is understanding what types of fermentations (and therefore, what general flavor profiles) are possible for a raw product, based on its basic makeup of proteins, sugars, fats, starches, and water. The other part of this is understanding what temperature and humidity ranges, acidity, salt, sugar, alcohol, and oxygen levels or additions are necessary for creating a hospitable environment for particular types of microbes to grow and ferment happily while excluding others.

The flavors produced by fermentation (see table) are diverse and often radically different from those of the ingredients we start with. Many of them are produced directly from the fermenting microbes' digestive processes. When these microbes extract energy from their surroundings, sugars are converted to alcohols and acids and large, relatively flavorless molecules, like starches and proteins, are broken down into smaller pieces, which due to their new sizes and shapes have different tastes and smells.

Fermenting microbes have a lot of other metabolic processes that keep them alive besides 'eating'— they need to build and break down proteins, maintain their cell membranes, and deal with shortages and surpluses of different amino acids. The molecules they produce in doing these things (secondary metabolites) are often small,volatile, and have flavors, too: fruity, creamy, buttery, cheesy, winey, pickley, ferment-y, pungent, vinegary, bready, floral, sulfury, popcorny, rosy, vegetal, almondy, honeylike, leathery, haylike, spicy, and fatty flavors can all be created this way. Aging or heating fermented foods can lead to further reactions between fermentation by-products creating other, different flavors such as balsamic-y, burnt sugar, dried fruit, caramelized, toasty, chocolatey, malty, meaty, roasty, cheesy, and nutty. See the table below for more details on these flavors, molecules, and microbes responsible for them.

Flavor	**Example Compounds**	**Type of microbe**	**Type of fermentation**	**Formation (if known)**
sour	lactic acid	lactic acid bacteria	lacto-fermentation, miso	sugars converted into lactic acid
sour and pungent-smelling	acetic acid	acetic acid bacteria	vinegar, miso	ethyl alcohol converted into acetic acid
sweet	sugars- glucose especially	*Aspergillus oryzae*	koji	starches broken down into indicidual units (sugar molecules)
umami	free glutamic acid	*Aspergillus oryzae*	miso, garum	proteins broken down into individual units (amino acids, glutamic acid is one of these)
fruity	esters such as ethyl decanoate (generic fruity) or isoamyl acetate (banana-fruity)	Yeast, acetic bacteria, lactic bacteria	wine, beer, vinegar, miso	an alcohol produced from fermentation (ethyl alcohol, isobutanol, isoamyl alcohol) binds chemically with a fatty/organic acid (acetic acid, decanoic acid). Secondary metabolite related to cell growth and balances of oxygen, fatty acids, and other components that the cell takes-up
nail polish remover	ethyl acetate	yeast, acetic acid bacteria	vinegar, miso	acetic acid reacts with ethyl alcohol to form ethyl acetate
creamy	acetoin	lactic acid bacteria	lacto-fermentation especially but not exclusively dairy	byproduct of LAB consuming small amounts of citric acid for energy
buttery	diacetyl	lactic acid bacteria	lacto-fermentation especially but not exclusively dairy	byproduct of LAB consuming small amounts of citric acid for energy
cheesy (blue cheese)	butyric acid	*Penicillium roquefortii* + fat-degrading molds	anything with fats	whole fats broken down into free fatty acids (lipolysis)
old cooking oil/paint	aldhydes especially hexenal and nonenal	oxidation rather than fermentation	anything with fats	whole fats broken down into fatty acids, then oxidatively degraded into aldehydes
cheesy (parmesan)	aldehydes, hexanoic acid, others	yeast, lactic acid bacteria	lactic & alcoholic fermentations	
winey	"fusel" alcohols-butanol, isoamyl alcohol	yeast, lactic acid bacteria	lactic & alcoholic fermentations	byproduct of yeasts breaking down amino acids as a nitrogen source
pickley/ferment-y	4-hexenoic acid	lactic acid bacteria	lacto-fermentations	fatty acid metabolism
pungent/vinegary	acetic acid	acetic bacteria	vinegar	primary metabolite of acetic bacteria
bready	(several compounds)	yeast	alcoholic fermentations	
floral	phenethyl alcohol	yeast	alcoholic fermentations	metabolite of yeast breaking down amino acid phenylalanine
sulfur	hydrogen sulfide	yeast	alcoholic fermentations	byproduct of yeasts synthesizing sulfur-containing amino acids
popcorn/basmati rice	2-acetyl pyrroline	lactic acid bacteria, *Aspergillus oryzae*	lacto-fermentations & koji	
rose	phenethyl alcohol, phenethyl acetate	yeast	alcoholic fermentations	
almondy	benzaldehyde	yeast	alcoholic fermentations	
honey	large esters and phenethyl esters	yeast, possibly LAB	alcoholic fermentations & lacto-fermentations	
leather	phenolic compounds	yeasts	alcoholic fermentations esp at a higher temperature	

<table>
<tr><th>Flavor</th><th>Example Compounds</th><th>Type of microbe</th><th>Type of fermentation</th><th>Formation (if known)</th></tr>
<tr><td>hay/barnyard</td><td>4-ethyl phenol</td><td>Brettanomyces yeast</td><td>spontaneous alcoholic fermentations</td><td></td></tr>
<tr><td>spicy/smoky</td><td>4-vinyl guaiacol, 4-ethylguaiacol and other phenols</td><td>yeasts</td><td>spontaneous or warm-temperature alcoholic fermentations</td><td></td></tr>
<tr><td>fatty & coconutty</td><td>delta-decalactone and other lactones</td><td>yeast, lactic acid bacteria</td><td>alcoholic & lacto-fermentations</td><td></td></tr>
<tr><td>balsamic</td><td rowspan="11">Maillard Reaction Products</td><td></td><td rowspan="11">Aged products you started with koji</td><td rowspan="11">free amino acids (broken down proteins) reacting with reducing sugars (broken down starch/carbohydrates)</td></tr>
<tr><td>burnt sugar</td><td></td></tr>
<tr><td>dried fruit</td><td></td></tr>
<tr><td>caramelization</td><td></td></tr>
<tr><td>toasty</td><td></td></tr>
<tr><td>chocolate</td><td></td></tr>
<tr><td>malt</td><td></td></tr>
<tr><td>meat</td><td></td></tr>
<tr><td>roasted</td><td></td></tr>
<tr><td>cheesy</td><td></td></tr>
<tr><td>nutty</td><td></td></tr>
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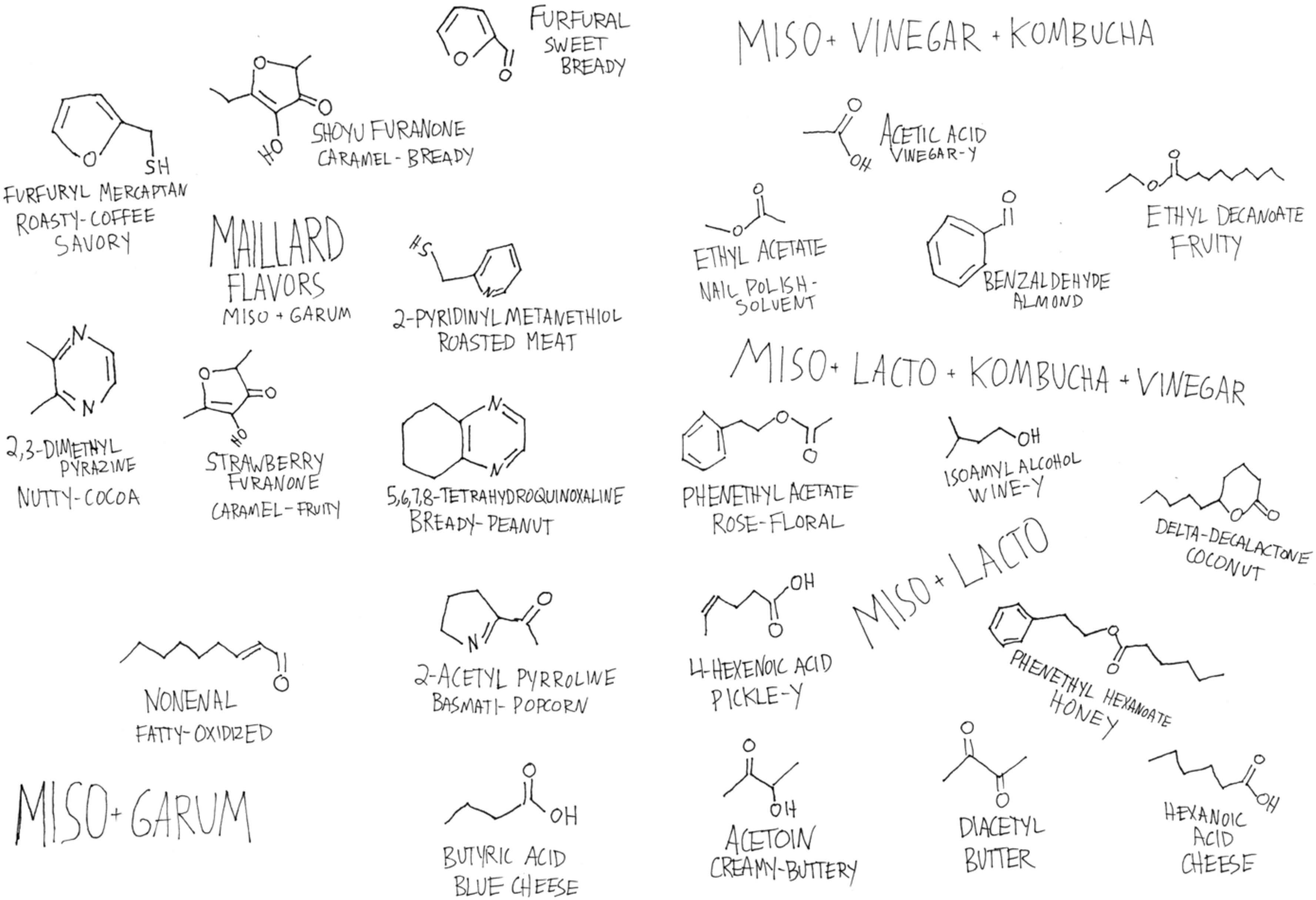

FURFURAL
SWEET
BREADY
MISO + VINEGAR + KOMBUCHA
SHOYU FURANONE
CARAMEL - BREADY
FURFURYL MERCAPTAN
ROASTY-COFFEE
SAVORY
SH
HO
ACETIC ACID
VINEGAR-Y
OH
MAILLARD
FLAVORS
MISO + GARUM
ETHYL ACETATE
NAIL POLISH-
SOLVENT
BENZALDEHYDE
ALMOND
ETHYL DECANOATE
FRUITY
HS
2-PYRIDINYL METANETHIOL
ROASTED MEAT
MISO + LACTO + KOMBUCHA + VINEGAR
2,3-DIMETHYL
PYRAZINE
NUTTY-COCOA
STRAWBERRY
FURANONE
CARAMEL-FRUITY
5,6,7,8-TETRAHYDROQUINOXALINE
BREADY-PEANUT
PHENETHYL ACETATE
ROSE-FLORAL
OH
ISOAMYL ALCOHOL
WINE-Y
DELTA-DECALACTONE
COCONUT
MISO + LACTO
OH
4-HEXENOIC ACID
PICKLE-Y
PHENETHYL HEXANOATE
HONEY
NONENAL
FATTY-OXIDIZED
2-ACETYL PYRROLINE
BASMATI- POPCORN
MISO + GARUM
OH
BUTYRIC ACID
BLUE CHEESE
OH
ACETOIN
CREAMY-BUTTERY
DIACETYL
BUTTER
OH
HEXANOIC
ACID
CHEESE

Notes

What microbes are we using?

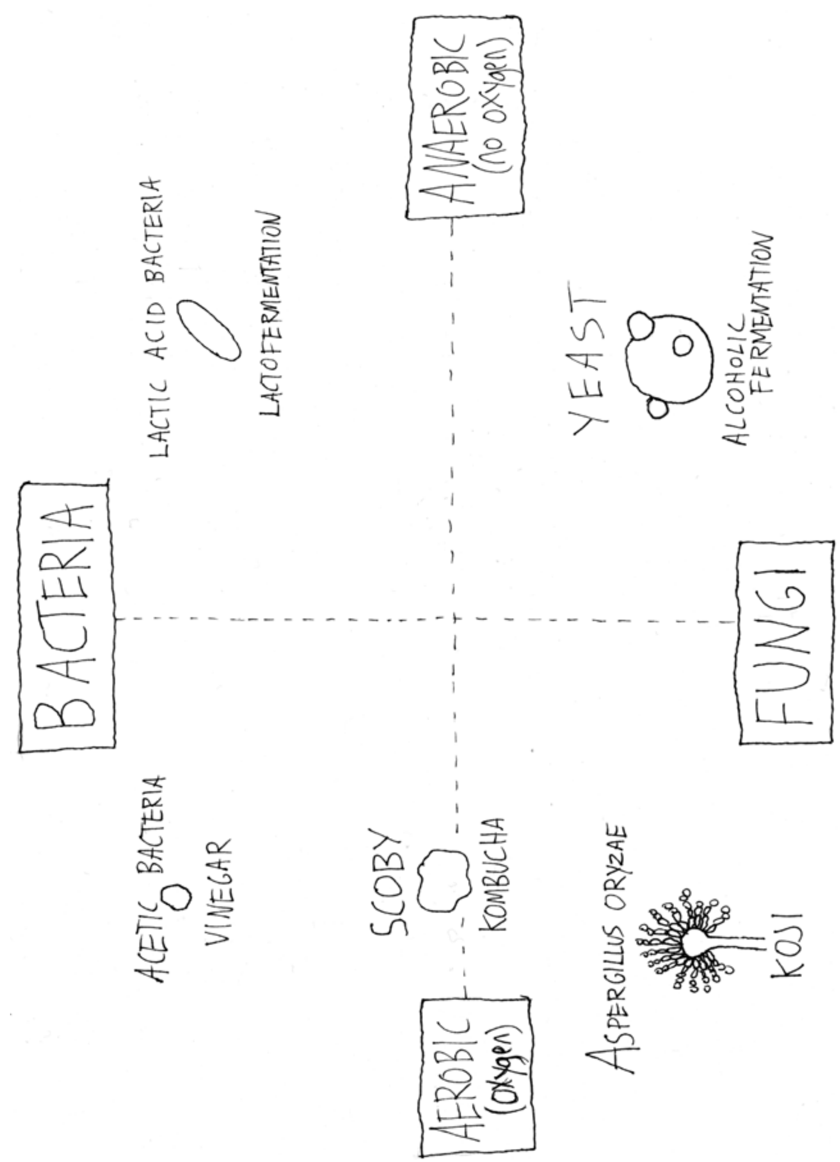
Most often, we're using lactic acid bacteria, acetic bacteria, molds, and yeasts (molds and yeast are both types of fungi). Fungi and bacteria are both microbes, but fungi aren't a type of bacteria and bacteria aren't a type of fungi. Therefore, in speaking about the fermentation process, using the term microbe, or micro-organism, will be the most correct.

So what is a bacteria and what is a fungus and when do I use them?

Acetic and lactic acid bacteria are, obviously, both bacteria; yeasts and molds are both types of fungi. We use wild lactic acid bacteria for our lacto-fermentation, which converts sugars into sour-tasting lactic acid. We use acetic bacteria to convert alcohol into acetic acid to make vinegar. We use yeasts like *Saccharomyces cerevisiae* and *Brettanomyces bruxellensis* to convert sugars into alcohol. We use *Aspergillus oryzae*, a mold, for the enzymes it creates to break starches into sugars and proteins into amino acids.

What is fermentation, please tell me in technical detail?

In the strict biochemical sense, fermentation is a metabolic process where microbes convert sugars into another substance in the absence of oxygen. In a colloquial sense, fermentation is the transformation of food by microbes and the enzymes produced by those microbes. The difference, basically, is that lactic fermentations and alcoholic fermentations are true biochemical fermentations, because they involve microbes converting sugars into lactic acid or alcohol in a process that doesn't involve oxygen. Since growing *Aspergillus oryzae* on grains, converting wine into vinegar with acetic bacteria, or doing controlled proteolysis of beef with salt and koji for a few months to make beef garum do involve transformation of foods with microbes and their enzymes, we call them fermentations in our day-to-day conversations and in this book.



How did all of these fermentations develop at noma?

Some time ago, we began to dedicate a significant amount of time to developing our 'toolbox' of fermentations at noma to explore the flavor possibilities in our region.

Pickling in vinegar developed early on as an important component of the noma larder— it is a simple way to reliably save the large amounts of plant products available in the spring, summer, and autumn months for the cold and fairly barren winter. Elderflowers and berries, ramson buds, and hip roses are all excellent pickled in vinegar, or heavily salted and then pickled in vinegar. The way these flavors changed, grew, and 'opened up' during this preservation process became an inspiration for investigating other types of fermentation processes as a path to new flavors. Souring and 'pickling,' lacto-fermentation, growing koji mold, Pea-so, grasshopper garum and then meat garum gradually were incorporated into the repertoire.

The current fermentation program is a logical extension of preservation techniques used extensively in Scandinavia for millennia. Salting, pickling, smoking, drying, and lye curing (a technique akin to nixtamalization), are all ancient techniques for preserving food in this region, and fall into what we loosely term 'fermentation.' The tremendous abundance during the summer needed to be preserved in order to survive the long harsh winters. Lacto-fermentations of milk products, such as skyr, were an important protein source, although far more critical were the sauerkraut type fermentations of vegetables as a source of necessary vitamins.

Anyway, it was a small cognitive leap to apply the sauerkraut process to other products like carrots, beets, and then every type of vegetable, fruit, mushrooms—more or less everything we could get our hands on, with various levels of success. Some of this was inspired by research into other cultures, whether the process, such as the multitude of steps involved in making a Japanese miso, or the product, such as the garum (salted fermented fish sauce) of Roman age. We began a series of trials with the ingredients around us, and the successes and failures led us to look into what was happening on a fundamental level—thus making the leap from merely considering the fermentations as individual products to using them as a set of tools with which to manipulate and shape raw materials, as one would use a knife or saute pan.

The garums began as a series of rather awful failures with mackerel and herring. Oily, evil tasting 5 liter containers of salted fish oozing yellowish fat. Obviously there was room for improvement— what could we change? The garum-style ferment is an enzymatic one, carried out by the digestive juices of the fish's own stomach. The trials we had been doing with miso involved making a molded barley with *Aspergillus orzyzae*, which develops enzymes to break down starches for a food source, but also produces enzymes to break down proteins as a secondary metabolic process. In the case of miso, this is used to break down the proteins in the soybeans to simpler amino acids, particularly glutamic acid. It occurred to us that this moldy barley could be the tool to better process the offcuts from fish. Within 10 weeks we had a far more tasty garum, dark and full flavored as a quality Nam Pla, which often takes a year or two to age properly. Unfortunately, the fats from these oily fish were still present, and lent a distinct 'harbour' harshness to the garum, so it could not be qualified as a success. We were able to eventually remove the bulk of these via ice filtering and centrifuging the solution, but we felt that the process itself was stronger than the particular product it had produced.

In a sense, we had created a 'tool' of a recipe—a certain amount of molded barley with its enzymatic properties to break down proteins, water to absorb the flavor, and a certain amount of salt to limit the types of fermentations to one: enzymatic. All that was missing was a main ingredient to slot into our new 'tool.' At the time, the closest thing at hand (laughably, in retrospect) was a kilo of grasshoppers, as we were, and still are, confounded and compelled by the lack of insects in the Western diet. Into the blender they went, and into then into the recipe 'tool' of barley, water, salt and temperature of 50°C. At the time we were using a second-hand heating blanket (like grandma had) and an old flamingo box, which René found hilarious, as he had never seen a heating blanket before. Within 10 weeks, we had a rich, malt colored liquid with intense soya-like umami, but also with touches of dark, almost Mexican mole-like flavors. We thought this one qualified as a success. From here on, we more or less stuffed every type of protein we could think of into our new 'tool'—shellfish, chicken, pork, crustaceans, lean fish, liver, eggs, cod sperm, etc and etc. Most were okay, some were horrifying, but some were real successes. The offcuts of squid, the bits and scrap that normally wound up in the bin, transformed into an unctuous jet black delight. Beef scraps formed an intense liquid with all the punch and nuances of a well hung rib eye steak.

The particular nascence of our garum, and the resulting development into the product range which we now have and continue to expand, is emblematic of how we strive to develop new techniques and foundations for the menu. A bit of inspiration from Ancient Greece, quick trials to get a feeling 'in the fingers for the process'— followed by some childlike curiosity and child-labor-like hours of hard work culminated in a win.

Although we have now been incorporating these techniques into our menu for many years now, we still feel that we are merely scratching at the surface; that a depth of possibilities still waits to be discovered.

Chapter Two

Lacto-fermentation

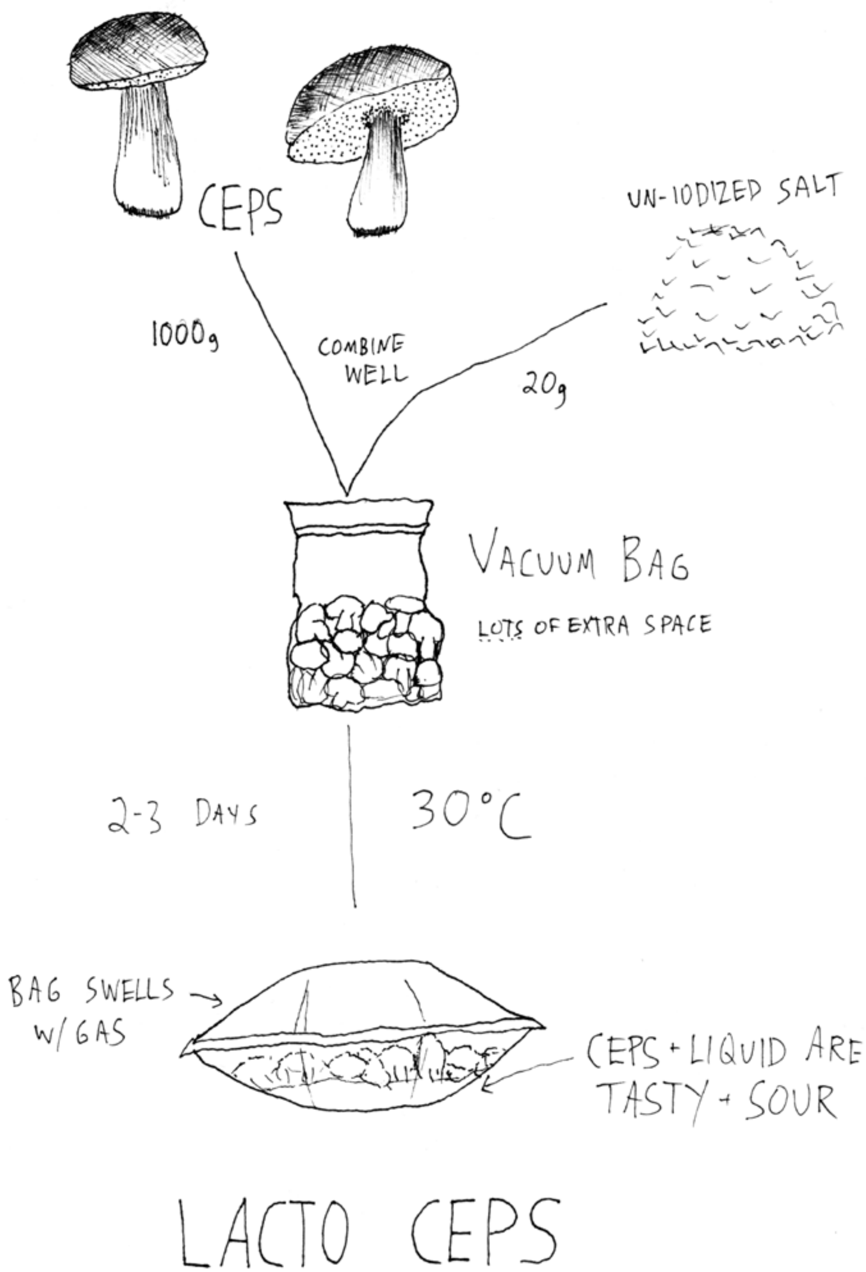
Salted and soured fruits, vegetables, mushrooms, grains, etc.

Process:

Sugars fermented into lactic acid by lactic acid bacteria, usually in a slightly salty and anaerobic environment

Necessary components:

Raw produce, salt, vacuum bag



Basic Recipe: *Lacto-fermented plums*

1000g Red Plums, preferably organic
20g Fine Salt (no iodine)

Weigh washed, cut in half, and seeded plums. Calculate 2% of the weight of the plums (so, 20g if you have 1 kilo of plums) and add that amount of fine, non-iodized salt to the plums. Gently combine the plums and salt so that the salt is very evenly distributed.

Lay the salted plums neatly in one layer in a very large vacuum bag, so that there is adequate space left in the bag for the gas produced by the lacto-fermentation to expand. Seal in a vacuum sealer, removing all the air.

IMPORTANT: *Don't try to lacto-ferment with less than 1.5% salt, it will probably turn yeasty or moldy and you'll have a bad time.*

Put the sealed bags in a secondary container (think cambro, not milk crate), in a room where they will stay at 25°C, and check the bags every day. When they swell up like balloons, open them and taste the fruit.

When the fruit is ready, it will be somewhat salty, softer than when you started but not mushy or disintegrated, tangy, and have a somewhat pickled flavor.

Lacto-fermentation Notes

Why a big vacuum bag?

Lacto-fermentation needs to be protected from oxygen, and produces a lot of carbon dioxide gas (which needs space to expand).

Why 2% salt?

A salty environment inhibits the growth of most spoilage bacteria and yeasts, but lactic acid bacteria have a much higher tolerance to salt. This way, you're suppressing the microbes you don't want and encouraging the ones you do. For a while, we experimented with salt levels between 0.5% and 3% for fermenting various ingredients and found that 3% salt tended to taste too salty, and that 1.5% and (especially) lower concentrations tended to let other microbial processes, like molding or yeasting, happen too often. 2% is a happy medium between salty flavor and controlling the fermentation.

Why shake the bag?

To make sure the salt coats all the fruit and mixes with the juices to make an evenly salty environment.

Why seal the bag under vacuum?

Many spoilage bacteria need oxygen to grow; this prevents unwanted foreign bacterial growth and also stops the fruit getting oxidized and browned.

Why put the bags in a cambro?

It's very possible that at least one bag will burst and leak. Since you put them in a cambro, you didn't leave a mess for someone else to clean up.

Why ferment at 25ºC ?

Colder temperatures will slow down the fermentation, while warmer temperatures can lead to spoilage or inferior flavor.

Why would I want to lacto-ferment something in the first place?

Lacto-fermenting ingredients helps preserve them and makes them quite usable even after they've been frozen. More importantly, it creates a lot of nice flavors: a very pleasant tanginess, for one, and also a really special depth and complexity. For instance, the Barley Koji is somewhat interesting on its own, nice smell, a bit sweet. But lacto-fermented, the Barley Koji is intensely fruity, the sweetness balanced by a complex sourness, a citrus fruit-white wine-noilly pratt reduction-tropical fruit, grain-broth lovechild.

How do I know when it's ready?

The level of "fermentedness" you're aiming for will depend on what you're fermenting and what you're trying to use it for. For instance, if you are going to ferment plums, the ideal starting point is a very ripe, yet still firm plum. When finished the plum will be a bit softer, yet still maintain a desirable texture, and a sweet/sour balance. Poor quality plums (say, which are a bit mealy and not that sweet) will fall apart into an average tasting sludge. If you are looking to ferment something like green gooseberries, the textures will be quite a bit firmer, both at the onset and completion of the process, and more care should be taken to balance the initial tartness of the berry with the eventual sourness.

What is happening here, microbiologically speaking?

Lactic acid bacteria (LAB) are eating some of the sugar in the fruit and converting it to lactic acid (which makes the fruit more acidic) and carbon dioxide (which makes the bag swell up). LAB are incredibly common in nature—they live on your skin, in the air, and on the surface of fruits and vegetables. Many of them have evolved to survive and grow in salty environments that would kill or inhibit most other microorganisms, including most spoilage bacteria/molds/yeasts.

Over the course of a lacto-fermentation, different species of LAB will dominate the process. Lacto-fermentation is usually kicked off by *Leuconostoc mesenteroides*, which begin consuming sugars and produce lactic acid, acetic acid, carbon dioxide, and ethanol, as well as a smaller amount of a variety of flavorful compounds. Once *L. mesenteroides* has raised the acid concentration to about 0.3%, *Lactobacillus plantarum* becomes the dominant fermenter, consuming sugar and producing lactic acid to reach levels of 1.5-2%. If there is any sugar left at this point, the fermentation is finished off by *Lactobacillus brevis,* which produces more lactic acid along with acetic acid and ethanol. This complexity is why temperature curves are often used in lacto-fermentation, especially with creme fraiche. Often the LAB is inoculated into cold cream, allowed to come to room temperature for 24 or so hours and then cooled down in the fridge- this changes the taste as some of the bacteria have their flavor profiles highlighted and others subdued.

Lacto-fermentation Trouble-Shooting

The fruit simply isn't getting sour:

Lactic fermentation is the conversion of sugars into lactic acids. If the fruit is not ripe enough, there is a lack of natural sugars, and the bacteria struggle to do their thing. Another possibility again originates in the fruit—if it has been sprayed with insecticides or fungicides, it is very possible that this is having an adverse effect on the LAB, especially its ability to produce acid. As we do not add a bacterial culture for inoculation, and depend on the wild strain native on the surface of the item to be fermented, the ideal product is organic and straight from the farm. Also check the salt you are using—there is some evidence that the iodine often added may suppress bacterial growth.

The fruit is moldy, or a white paste is seen, or a substantial boozy/wine flavor and odor is present:

This is most likely a salt problem. The amount of salt may have been incorrect. The bag may not have been shaken well enough to distribute the salt, leaving some parts of the product over salted, and some were left without protection from undesirable microbes. It is important to remember to lay the bags flat—the brine that results from the product losing water will protect it. If the bag is standing in such a way that the liquid is unevenly dispersed, then the fermentation will be equally uneven.

I tried a lactic fermentation of green plants and it tastes horrible:

There's often not a lot of sugar for the lactic bacteria to eat, and having prevented other microbes from entering the equation, the plant material simply decays. Furthermore, the small amount of lacto-fermentation that occurs tends to break down the already extremely volatile and delicate compounds that we associate with 'green', 'fresh' or 'grassy,' which are often part of the plant's defense system, and once broken result in 'swampy, moldy and more or less unbearably unpleasant.'

Lacto-fermentation Variations

Lacto Berries

Use a mixture of crushed and whole berries (crush half of them) so there's more liquid fermenting around the fruit.

Lacto Ceps

Freeze and then thaw cep mushrooms in a vacuum bag and ferment them as for fruit, above, with all the liquid they give off (use 2% of the weight of cep + liquid in salt). There will be quite a lot of juice at the end of the fermentation period. There are often multiple uses that come from the different aspects of the lactic fermentation. We often use the resulting liquid very differently than solid matter being fermented. For instance, with lactic fermented ceps the liquid is excellent for adjusting the acidity of savory sauces, or simply spraying/drizzling on vegetables or even seafood. The solid fermented ceps we may soak in birch syrup and dry into a chewy sweet/sour almost-candy. Or simply dry into a 'leather' that can be used as is, or cut into small intensely-flavored accents. Or added to something umami-rich like pea-so for a delicious paste.

Crème Fraîche

Lacto-fermentation is responsible for the tangy flavor of cultured dairy (yogurts, cheeses, creme fraiche, skyr, etc). It differs from plant product lacto-fermentation in that dairy lacto-fermentation is usually inoculated with pure strains rather than spontaneously fermented, is not necessarily salted to start the fermentation, and involves different species of lactic bacteria more adapted to metabolizing lactose (the primary sugar in milk).

Cured/Lactofermented Meats

Lacto-fermentation is an important process for preservation and creating flavor in cured meats, especially sausages and others made from ground meats. Since whole-muscle cured meats like coppa or prosciutto start as essentially sterile on the inside, any microbial transformations happen on or close to the surface, and not throughout the whole muscle. Either by fermenting the small amounts of sugars naturally occurring in animal tissue, or the additional grains, sugars, or powdered milk incorporated into the mixture, lactic acid bacteria create preservative properties and the sourness in summer sausage, nduja, and others.

Other incidental lacto-fermentations:

Lacto-fermentation is an important step in making miso—the creation of acidity out of the sugar liberated from starches by the koji enzymes (if this sentence makes no sense, take a look at the koji and miso chapters) is important for both the flavor development and preservation of miso. This is a slower process in misos than in fruits or vegetables, generally, because misos have a higher salt content. Lactic acid bacteria are the main fermenter in water kefir grains (also called tibicos) and are also present, though not the most dominant fermenter, in kombucha. There exist lactic acid bacteria that happily live in alcoholic environments that play a role in the winemaking process, feeding either from the grape sugars or from citric and malic acid. These can play a desired role, softening the acidity of the wine, or can create strange properties like a "mousy" aroma or stringiness from ropy polysaccharides.

Notes

Notes

Kombucha

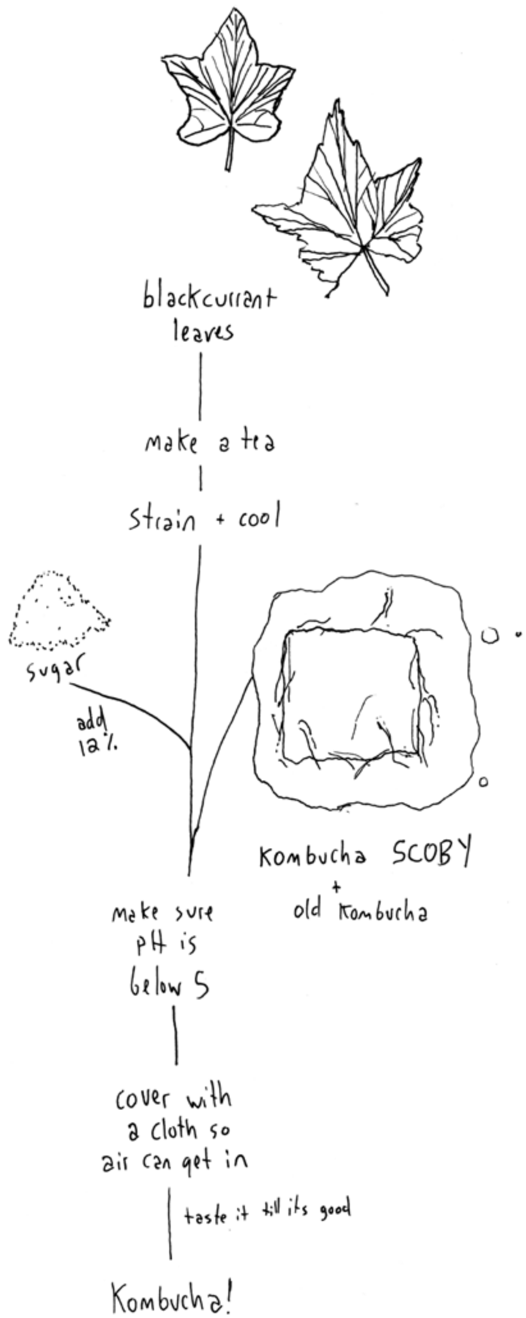
A slightly sweet, lightly acidic beverage

Process:

Flavorful sugar solution such as tea or juice fermented into acetic acid by a symbiotic colony of yeast and acetic bacteria

Necessary components:

Sweet liquid, kombucha mother/SCOBY, air



Basic Recipe: *Herb Kombucha*

- 1000g Filtered Water
- 5g Dried Tea or Herbs
- 120g Sugar
- 100g Previously Made Kombucha
- Kombucha Mother (SCOBY)

Make a 12% (12 Brix when measured by a refractometer) syrup of water and white sugar (120g of sugar for every liter of water).

Calculate 0.3-0.5% (3 to 5 grams per liter) by weight of the syrup and add that weight of dry herbs to the syrup. Heat together to 80°C to infuse for 5 minutes.

Strain, cool, and add a kombucha mother, also called a pellicle or SCOBY, which looks like a floppy mat or jellyfish, and enough already-made kombucha to lower the pH to 5 (measured with a pH meter). This should be approximately 10% of the total liquid weight.

Cover the mixture with a clean cloth (not a sealed lid) and let sit at 20-22°C for 7 to 10 days until the kombucha is acidic and slightly vinegary. The pH should be 3.7 by a pH meter. Unless for a specific use that requires it to be very acidic, use, refrigerate, or freeze before the kombucha is aggressively vinegary.

Store the SCOBY that has formed in the kombucha in a container covered with more kombucha until you need to inoculate another batch.

When the kombucha is ready it will be noticeably sour and have some vinegar aroma, with a bit of residual sweetness. If it is very sweet it is not finished yet; if the vinegariness is very irritating or pungent, it is over-fermented.

Kombucha Notes

Why syrup?
The microbes that ferment the kombucha feed on sugar.

Why herbs?
Because you want it to taste like something, right? The herbs may be dried, like a tea, or fresh, like pineapple weed. Black tea is traditional, herb teas and juices will also work. But the only requirement is that the product be flavorful and have the appropriate Brix. We have made a very sucessful infusion of the husks of black garlic- delicious taste and the residual garlic paste provided enough sugar in itself.

Why is it cooled after infusion?
If you add a starter to a hot liquid, the microbes will die.

Why start at pH 5?
Lower pH = more acid, which is inhospitable to mold, etc. Kombucha higher than pH 5 tends to get moldy.

What the hell is a SCOBY?
Kombucha is fermented by a colony of yeasts and bacteria (kind of like sourdough). They form into a slimy mat as they grow, called a mother or a scoby. You make kombucha by using a mother from a previous batch, and adding the whole mat into a fresh batch of sweetened tea.

Okay, but why do they call it a SCOBY?
SCOBY is actually an acronym that stands for Symbiotic Colony Of Bacteria and Yeasts. A SCOBY is usually found as multiple species of bacteria and yeasts bound together in a slimy mat or biofilm of hydrocolloidal cellulose secreted by the microbes.

What if I want to store my SCOBY for a long time?
You can also store the mother in the fridge, covered in kombucha. It will essentially go dormant and will require a few days in sweetened tea, at room temperature, with access to oxygen to get back up to speed when you want to use it again.

How does kombucha fermentation work?
There are various species of yeasts and bacteria in the SCOBY that gets added to the sweetened tea. The yeasts ferment the sugars in the tea into alcohol, and the bacteria consume the alcohol and produce acetic acid, converting a sweet liquid into an acidic, slightly alcoholic one. The yeasts present include *Saccharomyces* and *Zygosaccharomyces*, and the bacteria include the acetic bacteria *Acetobacter* and *Gluconacetobacter*, and frequently include lactic acid bacteria as well.

Why isn't this kombucha fizzy like other kombuchas you can get for drinking?
Kombuchas that you buy commercially have usually been re-fermented in the bottle; the yeast part of the fermentation produces carbon dioxide gas, which makes the drink fizzy if the container is sealed and the gas builds up. This kombucha recipe isn't directly intended for drinking as a fizzy beverage, but you can make it into one by putting it in a closed container that can hold pressure (for example, clean old soda bottles) when it is still slightly sweet and letting it re-ferment in the bottle.

What if I want to make Kombucha but don't have a SCOBY or mother?
The short answer is, you can't; you need kombucha to make kombucha. If you have an unpasteurized, already-made kombucha, you can inoculate a new batch of kombucha with that successfully, though it can be a somewhat slower fermentation process. If you have neither on hand, it's possible to order a SCOBY online.

Kombucha Trouble-Shooting

There is a stringy jellyfish-looking translucent horrible thing floating in my kombucha:

That is unfortunately what the SCOBY looks like. It shouldn't be fuzzy, moldy, black, or other strange colors though.

The SCOBY looks fuzzy or moldy, or smells cheesy:

It probably got infected with mold: If you can peel off the top layers of the Scoby and throw them away, the bottom part might be salvageable. To avoid this, make sure the top of the SCOBY doesn't get too dry (ladle a little kombucha over it as it ferments), and make sure the liquid you're making into kombucha is at least somewhat acidic (pH below 5) to stop molds from growing. Also, if there is not enough sugar, the Scoby can die, or not grow fast enough to compete with the molds.

The kombucha tastes like straight vinegar:

When the kombucha scoby ferments, it is eating sugars and creating alcohol, then converting the alcohol to acid. If you let it go too long all the sugars will get converted into acid. You can't really reverse this process but the kombucha is still OK to use to start a new batch. This is also a method for creating something rather close to a traditional vinegar, but much faster.

Kombucha Variations

Fresh herbs can be added to the sweetened tea + SCOBY for cold infusion to add extra depth of flavor. Honey can be used as the sugar source—but since honey often harbors a wide range of wild yeasts and other microbes, you should boil the honey-kombucha base so the SCOBY microbes don't have to fight off other species to do their thing.

Lemon Verbena Kombucha

Use lemon verbena or a mixture of lemon verbena and lemon thyme in the above recipe.

Blackcurrant Leaf Kombucha

Add dried blackcurrant leaves at 5 grams per liter (0.5%) to infuse in water at 70°C for 25-30 minutes (sealed or covered in plastic wrap), strain, and then sugar added at 100 g/L (10%). Add kombucha mother and ferment, as above in basic recipe. (Blackcurrant leaves are not as aggressively flavorful as verbena and other herbs, and require a higher ratio and longer steeping time)

Elderflower Syrup Kombucha

Adding a kombucha mother to elderflower syrup containing 30% sugar (30 Brix) will make a very sweet elderflower kombucha. Diluting this syrup to 15 brix makes for a lighter, more traditional-tasting, drier kombucha.

Juice Kombucha

Juices (carrot, apple) can be used to make juice kombucha. The carrots you use should be as sweet a variety as possible; check the brix of the juice and adjust if it is below 8-10 brix. Apple juice makes a very delicious kombucha.

Rose Pulp Kombucha

This is a Kombucha that we make from the left-over pulp from a rose oil production, which is simply wild beach roses blended with oil. Once the oil had been fully pressed out of the pulp, we mix that pulp with a 12% sugar solution, allow it to steep overnight, strain the liquid (taking care to skim the oil) and use that as a base for the Kombucha.

Milk Kombucha

Milk, with a good deal of care, can be used to make kombucha. It is critical to incorporate a sufficient amount of liquid mother in the form of a previous batch of kombucha, without lowering the pH too much. With some attention, it is possible for the kombucha to thicken the milk and lend a pleasant acidity. If the fermentation is allowed to continue for too long, the pH will drop too low, denaturing the proteins and splitting the milk. If the milk Kombucha spends only 2 days at 20°C and then put in the fridge, it's possible to set it, like a fresh cheese.

Kombucha Crème Fraîche

800g Milk
200g Cream
200g Kombucha- Elderflower Kombucha works very well for this.

Incorporate the ingredients. Ferment at 20°C for one day, then place in the fridge to finish fermenting for two more days.

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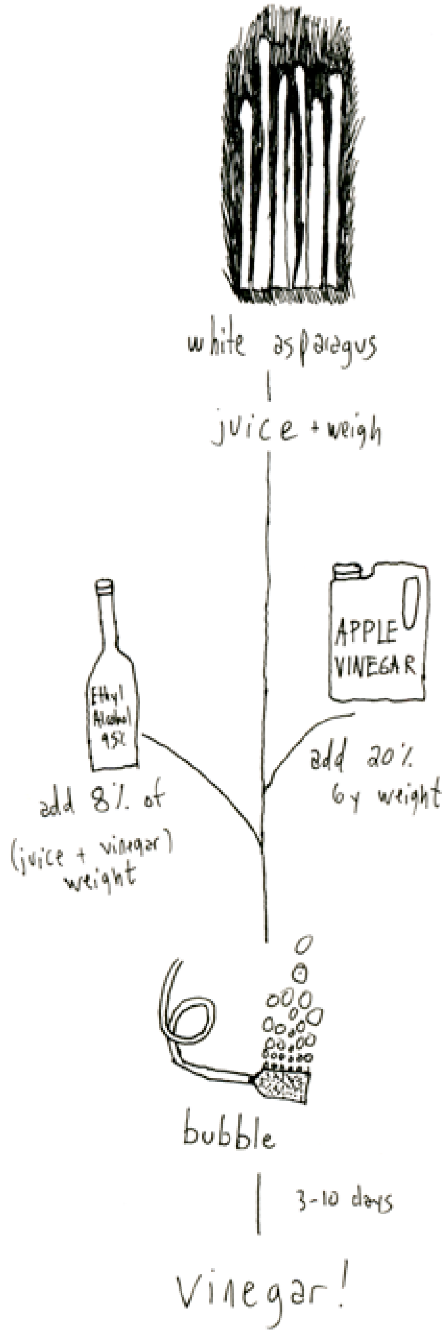
Chapter Four

Vinegar

Sour liquid fermented from an alcoholic mixture

Process:
Ethyl alcohol fermented into acetic acid by acetic bacteria, with lots of oxygen

Necessary components:
Liquid, alcohol, vinegar starter, air



Basic Recipe: Single-Step Juice Vinegar

1000g Juice
200g Unpasteurized Vinegar
96g Ethanol

Weigh the juice. Calculate 20% of this weight and add that amount of unpasteurized vinegar. Calculate 8% of the total weight you have (juice + unpasteurized vinegar) and add that amount of high-proof (96%) ethanol.

IMPORTANT: *the alcohol you add MUST be food-grade. Everclear, overproof vodka or rum, or food-grade 96% ethanol are all fine. Anything labeled "100%" or "Denatured" will contain unsafe or poisonous substances. Perversely, "100% Ethanol" has had benzene or something else nasty added to it to de-water it and should therefore be avoided. It's only possible to get 95-96% ethyl alcohol via distillation, so this is the highest possible purity you will be able to find that hasn't definitely had something weird done to it. If it says that it has had isopropyl alcohol or methyl ethyl ketone or any other chemical name that's not ethyl alcohol or water added to it, don't use it for food. Ethyl alcohol for torches or stoves should NEVER be used to make vinegar.*

Put the mixture of juice, unpasteurized vinegar, and ethanol in a container large enough that it leaves you some headspace, about 25% of the total volume of vinegar.

Take an aquarium air pump, attach tubing and an airstone, and bubble the mixture with the airstone.

Cover the container with cheesecloth, netting, or a blue cloth to let air in and keep flies out.

Don't ever totally seal a container of in-process vinegar. Oxygen is essential for the fermentation to work.

Taste the vinegar every day. When it is finished it will be vinegary but should still have some of the fresh taste of the juice you started with. If it is still very hot-alcoholic, or smells like nail polish remover, it should be bubbled and oxygenated more.

Vinegar Notes

Why add unpasteurized vinegar?

Raw (unpasteurized) vinegar has acetic bacteria living in it, and so it acts as a starter or inoculant to get the fermentation going. Vinegar also makes the fermentation mixture a more hospitable environment for acetic bacteria to chill out and grow in.

Why are we adding alcohol?

The alcohol is what gets turned into acetic acid by the acetic bacteria. No alcohol, no vinegar.

Why an aquarium air pump and airstone?

Acetic bacteria need oxygen to live, and by bubbling in lots of oxygen they can create vinegar in about a week instead of a few months, which is how long it often takes without aeration.

Advanced Recipe
Elderflower and Elderberry Wine Vinegar

Elderflower Wine Fermentation:

Take a tube of White Labs WLP 650 (*Brettanomyces bruxellensis*) or WLP 568 (Belgian Saison Yeast Blend) yeast out of the fridge to come to room temperature before you begin. WLP 650 will make a sweeter vinegar, and WLP 568 will make a drier vinegar.

Take 8.5 L of elderflower syrup that is 60 Brix and put it in a 30-L bucket (which you have already sprayed down the inside of with food grade alcohol) with 8.5 L of filtered water. Measure and write down the exact Brix level; it should be about 30 (28-32) Brix but make sure you note the exact value and write it down on the bucket. You will need this initial measurement later to gauge how far the fermentation has gone.

Gently shake the tube of yeast to make sure the yeast sludge that is caked on the side is fully suspended in the liquid. Pour the entire tube of yeast into the bucket, stir it well (with a clean, alcohol-sprayed whisk or spoon) to incorporate and aerate it slightly, and put the lid on the bucket with an airlock in the lid. Make sure the airlock is filled with water to the line, and that the airlock is capped.

As the yeast ferments the sugars in the elderflower syrup, the lid will puff up slightly and the airlock will slowly bubble.

As the fermentation progresses, check the Brix value with a refractometer every few days. Enter the starting brix (which you wrote down, right?) and the current brix into the “Monitor Ferment Progress with a Refractometer” calculator available online at the website VinoCalc http://www.musther.net/vinocalc.html#monitorferment, and read Residual Sugar and Current Alcohol values it calculates. For a sweet vinegar, the alcohol percentage should be between 2% and 4% alcohol. For a dry vinegar, the alcohol percentage should be between 8% and 10% alcohol.

Elderberry and Vinegar Fermentation:
Once the wine has been fermented to the desired level of alcohol, inoculate with vinegar starter and add elderberries.

For a sweet vinegar (with WLP 650 Yeast): add 3600g of apple vinegar and 2125g of ripe elderberries (stems removed) to the 30-L bucket with the wine.

For a dry vinegar (with WLP 568 Yeast): add 4250g of apple vinegar and 9000g of ripe elderberries (stems removed) to the 30-L bucket with the wine.

Keep the lid off of each bucket and cover the open bucket with cheesecloth or other breathable material, and tie off the material so it is secure and flies can't get in. Let the vinegar age and ferment for 3-6 months at 25-30°C. Stir in the elderberries that float to the top periodically.

More Vinegar Notes

Why do we start with sugar and yeast?
We need alcohol to make vinegar. Instead of adding alcohol to juice directly like for a single-step juice vinegar, we're using yeast to convert sugar into alcohol, then converting that alcohol into acetic acid.

Why does the elderflower syrup get diluted?
With too much sugar, the yeast will either not be able to ferment at all, or we would get a ridiculously alcoholic, ridiculously sweet wine. But the syrup will be more stable and takes up less space for storage if it is 60% sugar.

How do you decide to do a yeast fermentation or add alcohol?
Key questions to ask yourself are,

- is the ingredient you want to make into vinegar yeast-fermentable—does it have sugars in it?
- will the flavor changes that occur during yeast fermentation add or detract from its flavor?
- how delicate or unstable is the ingredient you're using?

If you had grapes, you could juice them and add alcohol, but it wouldn't taste anything like wine, and a vinegar you'd make out of this would be quite sweet compared to wine vinegar and lack complexity. On the other hand, things like celery, asparagus, or pumpkin have some sugar in them, but not enough to make enough alcohol to get a stable vinegar. Generally 8% alcohol will make a good, stable vinegar; sugar levels of at least 14 Brix are necessary to reach this level of alcohol. Celery juice, if it sits at room temperature for too long (which it would have to to ferment into wine), tends to lose some of its fresh flavor and get muddied, and doesn't necessarily benefit from having a winey background flavor. Most of this we figured out by trial and error, but generally the more green/vegetal an ingredient is, the less likely it is to be good as a wine, and the sweeter/more tannic/fruity and concentrated an ingredient is, the more likely it is to be good as a wine.

What's the deal with the yeast?
Like many of our techniques, we picked these yeasts empirically, i.e. through trial and error. Saison yeast is a blend of yeasts that includes *Brettanomyces* species as well as the more standard *Saccharomyces cerevisiae* (which is the species typically used for wine, beer, and bread). *Brettanomyces* is a genus of wild yeasts that are pretty slow fermenters, and adds some complexity via very subtle barnyard-y and funky flavors (these flavors are much more pronounced in wines and beers with a significant Brett-fermented component). This isn't to say that regular wine or beer yeast won't work, though.

Where can I find more information on alcoholic fermentations?
Generally, we only produce alcohol at noma to eventually ferment it into vinegar. We've experimented with beer-brewing and mead and winemaking; but, generally, unless it's destined for vinegar, we leave the production of alcohols to our more talented friends like Mikkeller or Aqua Vitae Sydfyn, not to mention our many wine suppliers.

Why is this one not bubbled with an aquarium pump? How do you decide to do an active or a passive aeration?

Some ingredients make a better vinegar if they are bubbled or otherwise aerated to very rapidly acetify them, other make a better vinegar if they age for a while and acetify slowly. Generally, lower-sugar and lower-acid, vegetal or green-tasting ingredients (such as squash and pumpkin, celery, fennel tops, asparagus, parsley) are make better fast vinegars: the fast increase in acidity helps protect them from mold and other sources of off-flavors, and once they lose their fresh flavors they don't really develop more complexity. More winelike, fruity, or already-fermented ingredients (elderflower wine, elderberries, beer) often develop complexity by a more drawn-out fermentation and so can make a good vinegar either by passive or active aeration.

Vinegar Trouble-Shooting

The vinegar is boozy and not very acidic:

You probably need to wait longer. Acetic fermentation can be somewhat slow especially if you're not bubbling air through it. If you need it very soon, try bubbling a lot more air through it. Also, sulfur added as a preservative to wines and some beers, fruits, etc. will inhibit the growth of acetic acid bacteria—so try to start with more natural, unsulfured stuff to begin with.

The vinegar tastes like nail polish remover:

It might not be finished, or it might not be getting enough air—the nail polish remover comes from leftover alcohol reacting with the acetic acid. Try airing it out or bubbling more air through it, or leave it and check again in a few days.

Vinegar Variations

Juice Vinegars

Pumpkin juice, white asparagus juice, celery juice, and fennel top juice all make great vinegars.

Tea Vinegars

Pine tea and other teas work as a substitute for the juice in the above recipe.

Wine or Beer Vinegars

If you have wine already, like cherry wine from Frederiksdal, you can use that with 20% vinegar starter and skip adding any additional alcohol. This technique also works with wine you make yourself, beer, sake, etc.

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Koji

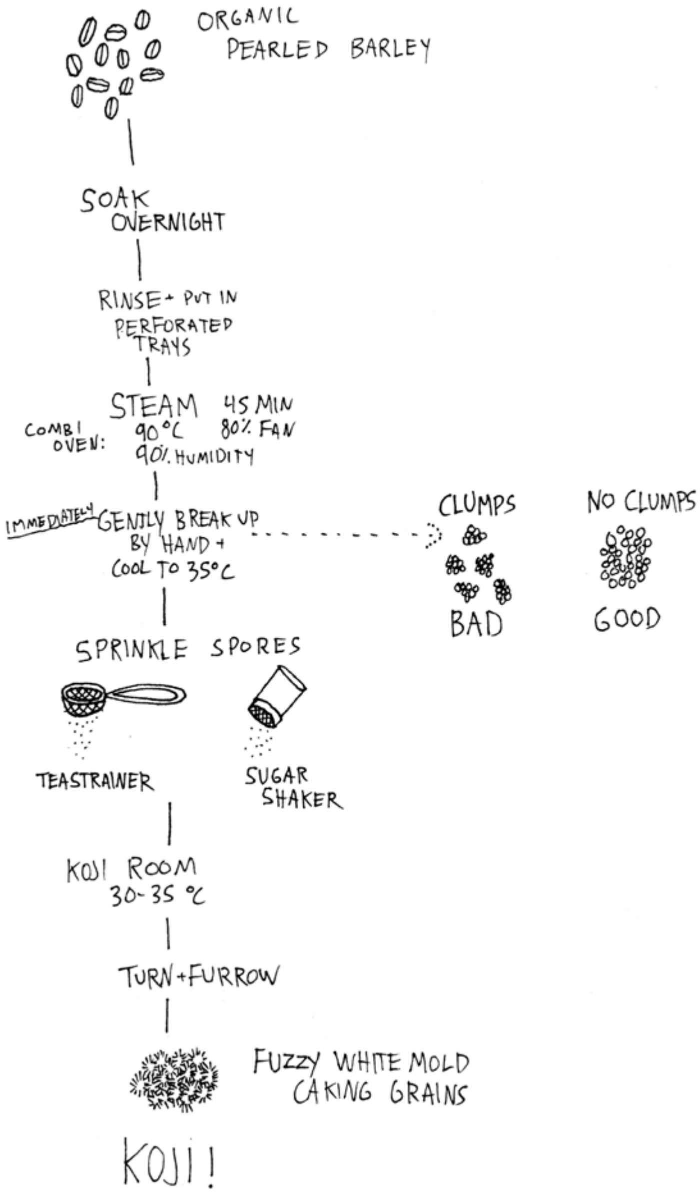
Steamed then mold-inoculated grains

Process:

Aspergillus oryzae mold grows on grains, breaking down their starches and proteins for food, releasing useful enzymes in the process

Necessary components:

Grains, steam oven, Aspergillus oryzae spores



Basic Recipe: Barley Koji

Steaming

Soak pearled organic barley in cold water in the refrigerator overnight.

The next morning, put the soaked barley in perforated gastro trays, rinse it with cold water in the sink, and steam it in the combi oven at 92°C, 90% humidity, and fan speed 80%.

Take the barley out of the oven, and break it up gently into individual grains with your hands while it's hot, which helps stop it from getting too wet and clumpy (try wearing two pairs of gloves to do this). Discard any barley that's become very soft and overcooked from pooling water or condensed steam. All the grains should be separate, cooked through, and firm, but not soft, mushy, or slimy.

Inoculation

Divide the barley up into several perforated gastros in a depth of about 4 cm. Wearing gloves, put spores of *Aspergillus oryzae* into a small tea strainer and tap the strainer over the cooled steamed barley. Do one light pass with the spores in the tea strainer, mix/fold the barley with your hands to incorporate the spores, then do two more light passes each followed by folding the barley to mix the spores in. If you're using spores you grew yourself, put the dried sporulated koji in a powdered sugar shaker and shake it on in three passes.

Mold Growth

Cover each tray with a very clean cloth that you've soaked in water and wrung out well. Put the trays of inoculated barley in a clean, warm room (not an oven) with the temperature set to 33°C and humidity of at least 80%. Ideally, temperature should be controlled through a PID box; insert the temperature probe into the inoculated barley for the duration of the mold growth phase.

EXTREMELY IMPORTANT: *During the mold growth process it is very easy for the koji to overheat and kill itself. WATCH THE TEMPERATURE of the koji and make sure it doesn't go above 39°C.*

After about 24 hours, the barley should be showing some visible mold growth. Gently crumble it with your hands into individual grains, fold the outer grains into the center of the tray so it is well-mixed, and make two shallow, evenly-spaced furrows all the way down the middle of the barley in the long direction to make three long rows of heaped barley in the tray.

Let the mold grow on the barley for about 12 hours more, until the white mold of the Aspergillus binds the barley together into a solid cake and looks slightly fuzzy. At this point, the barley will taste sweet and slightly fruity, with a savory and mushroom-y aftertaste. Try to stop before it looks extremely fuzzy, with tiny balls of mold among the mold hairs— at this point, it is starting to produce spores (sporulate) and won't be as tasty or effective.

Use the koji right away or refrigerate for up to three days. Cool the koji in its trays in the walk-in before putting it in a container. To store for longer, put it in vacuum bags, freeze, and then seal to store in the freezer.

Koji Notes

Why pearled barley?

Removing the barley husk makes it easier for the mold to reach the starch in the grain, and it will ferment the grains more completely. It's possible to make un-pearled or unpolished grains into koji, but they tend to sporulate faster and don't get as sweet.

Why soak and steam the barley?

The ideal medium for growing *Aspergillus* is hydrated, but separate and relatively firm grains. Boiling the grains tends to over-hydrate them and make them too wet and mushy. This makes it too easy for the mold to grow quickly just on the surface instead of expending energy to produce enzymes to penetrate to the middle of the grain. We want the enzymes so we want to create conditions that make it a little trickier for the mold cells to grow too fast. Over-hydrated grains also tend to stick together and create poor conditions for airflow, choking and killing the growing mold below the immediate surface layer of the grains

Why crumble the barley up by hand?

This ensures that the barley cools off evenly and gives up its extra moisture, that each grain gets evenly coated with spores, and that air can get to each grain.

Why inoculate with mold spores?

Unlike beer, sourdough, or other yeast and lactic fermentations, it's not possible to simply "back-slop" or inoculate a new batch of koji by adding a small amount of finished koji or miso to new barley grains. Instead, the mold has to be grown past the stage in its life-cycle when it's useful for miso, koji water, etc. and until it enters its reproductive phase and starts producing spores. These spores are like seeds for new koji, and by collecting them and sprinkling them on freshly steamed grains, you can grow a new mold colony (your koji!)

Why the high humidity?

The mold needs the environment to be relatively moist to grow properly, but not actually wet.

Why 33ºC?

The barley needs to be pretty warm for the mold to grow on it properly, and in the 30-35°C range it produces a lot of useful enzymes that break down starches into sugars (which are sweet and can be fermented) and proteins into free amino acids (which have an umami flavor and can break down into aromatic compounds).

Why furrow the inoculated barley?

Starting about 24 hours after inoculation, the koji can heat itself up to 40-45°C or higher, which is hot enough to kill the mold cells; furrowing helps dissipate some of this heat. The mixing also incorporates the parts where the mold is growing faster, leading to a more evenly fermented final product.

Why do I have to be so careful with the temperature?

Koji and *Aspergillus oryzae* are very sensitive to temperature—as mentioned in the recipe, the mold can give off enough heat during its growth phase that it can cook itself to death. But besides ensuring that your mold actually survives, controlling temperature will also determine how effective the koji is at second-stage fermentations you want to use it for. Pretty much all living cells produce enzymes, which are protein molecules that build, break down, or alter other molecules; they are the machinery that, on a molecular level, perform the processes that keep a cell alive. Enzymes are usually named as "the thing they break down"+ "ase." If you see a world ending in "-ase," there is a good chance it is the name of an enzyme, and the word(s) coming before "-ase" describe its function or the molecule that it breaks down. The two classes of enzymes in koji that are most useful to us are proteases and amylases. Proteases break down proteins into their component amino acids, and amylases break down starches (made of amylose and amylopectin) into their component sugars. These processes are useful because free amino acids are delicious and taste like umami, and they also break down and react with other molecules to make new molecules with complex flavors; sugars are also tasty, but more importantly can be fermented into new flavors by lactic bacteria, acetic bacteria, and yeasts. Whether the koji you produce is richer in amylases or proteases—whether it is more effective at breaking down proteins or starches—depends on temperature. Proteases are produced more effectively close to 30°C, and much less effectively at higher temperatures (38°C or higher), whereas amylases are produced well at both temperatures. To dial in a particular balance, it is essential to maintain precise temperature control of the koji while it is growing.

Why can't I just put it in the Rational or Combi Oven?

While a Rational can be set to 30°C, it has temperature spikes and drops when holding at 30°C. It will drop down to 20°C at some points, which is not great for keeping the barley growing; it will also spike to 40°C or more for about 10 minutes at a time, which will kill the mold and your koji. More gentle and precise temperature control is needed, which can be accomplished in a heated room or in a chest-freezer sized box, especially with the heating controlled by a PID box (the kind of temperature control that sous vide machines have).

Why all this fuss? Why do I want to make koji?

Acknowledgement: out of any of the techniques in this book, koji-making is probably the most finicky and the biggest pain in the ass to figure out. It needs to be exposed to air, but not so much that it dries out; it needs to be kept within a relatively narrow temperature range, which means warming it at some points of the process and cooling it at others; it needs to be kept very humid but not so humid that water starts to condense on the surface of the grains; it needs to be tended to at several time-points in its fermentation period; and the necessary amount of, and parameters for, soaking and steaming vary widely for more uncommon but interesting ingredients like buckwheat or bread. However, with a few technical interventions, it can be made pretty reproducibly. Currently we use a 3-4 sq. meter room, where a humidity sensor controls a fogger, and the temperature in the room is controlled by a PID box connected to a thermometer and an infrared heating panel. We've also used a broom closet with a space heater and home humidifier, and a chest freezer lined with an under-floor heating mat with heating and cooling cycles controlled by PID and open containers of water for humidity. A decent amount of air circulation is necessary for avoiding over-heating, so producing koji in small styrofoam coolers or thermal boxes is more likely to result in dead koji.

Once you put in the work and attention to make it, koji has possibly-endless, near-magical abilities to create flavors and transform other ingredients, enabled by the enzymes produced by *Aspergillus oryzae* as it grows. These break down large molecules into smaller components—starches into sugars, and proteins into amino acids. These molecules have flavors of their own, fuel further fermentation processes, and react and break down to make more flavors. Many of the most interesting uses for koji kill off the remaining mold cells (with salt and/or lack of oxygen) and hijack their enzymes to transform a second ingredient like peas, beef, or rye bread.

Koji Trouble-Shooting

The Koji is a solid, white slab or cake and smells pleasantly fruity/bread-y/ floral/ mushroomy and tastes sweet:
Congratulations, you did it right!

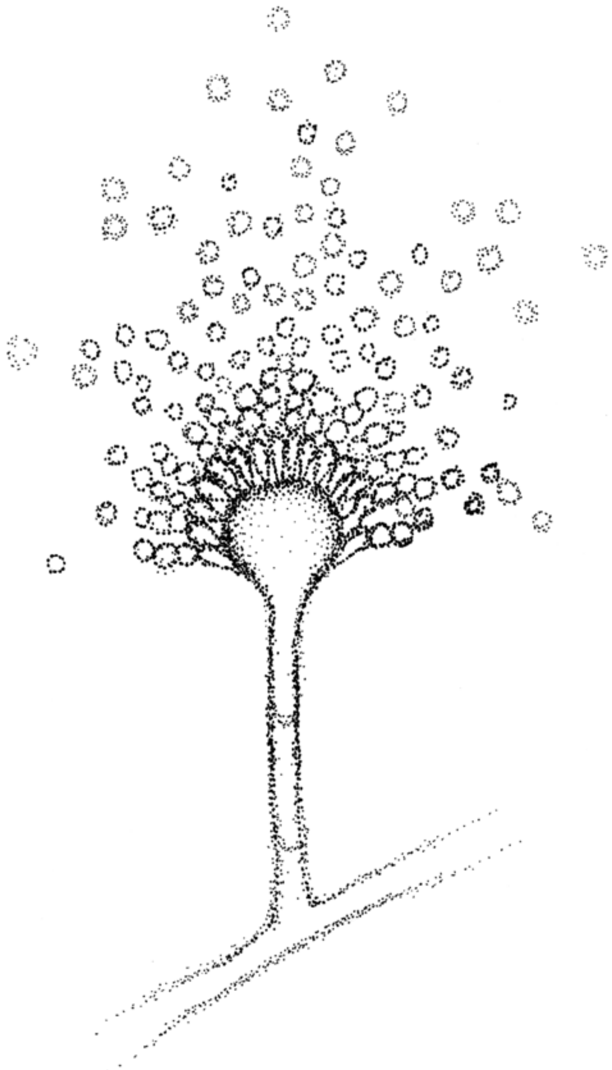
The Koji is slimy and smells like feet, rotting onions or something equally unpleasant:
The *Aspergillus oryzae* spores weren't able to grow, and a spoilage bacteria/ mold took over. This usually happens when the grains are too wet, and air can't get to the stuff on the bottom and it all kind of putrifies. If you boil the barley or whatever other grains you're using (quinoa, millet, buckwheat, anything with a husk that is hard to steam) this often happens. It's also possible that you didn't let the grains cool off enough before you inoculated them, and the Aspergillus died at that point. Definitely throw it out and start over.

The Koji is sticky and there's not really any mold growth and it smells like rotten banana/fruit:
The koji probably got overheated—if you start the growth in the early afternoon, this often happens in the morning or afternoon the next day - and this killed the *Aspergillus* cells, and a heat-tolerant bacteria called *Bacillus subtilis* started growing instead. This is useless for fermenting anything else and you should throw it away.

The Koji has a bunch of black spots or black fuzzy mold on it:
This seems to happen when the barley is too damp. Make sure that the perforated tray you're using has lots of holes that extend as far to the sides as possible to ensure maximum airflow and avoid condensation. Also make sure that you discard any barley that has become waterlogged and soft from being oversteamed before you inoculate. You'll often be able to catch a batch that's going to go wrong when you do the first turning; if you see any areas that are getting black specks on the barley, or that feel particularly sticky, discard these and the rest of the tray might still be usable. This might be a mutation in the *Aspergillus oryzae*—all koji molds started out as black and were bred and mutated to become white—or it might be another species; in any case, don't use it for anything.

The temperature of the Koji keeps going to 40°C or higher:
The koji produces heat as it grows. You need to keep an eye on the temperature and help dissipate that heat - break up the koji with your hands, fold it over itself, and make furrows in the barley. You can also try cooling the room actively at this point, and keeping some space around each tray for air to circulate and stop heat buildup.

I made Lacto Koji Water and it smells like rotten eggs:
First, throw it away and don't use it. Second, make sure you use twice as much water as koji and 2% salt, and check it every day. Also make sure that all your equipment/hands are very clean.



Aspergillus oryzae conidiophore (spore cell)

Uses for Koji

Lacto Koji Water

Take 500 g of finished koji, 1000g of filtered water, and 30g of fine salt. Blitz in a Thermomix to combine, and seal in a vacuum bag as close to 99% vacuum as possible without bubbling over. Let ferment for 3 days at 25°C until the bag is swelled. The Lacto Koji Water should taste clean, fruity, lightly acidic, and creamy, with no eggy aroma.

Roasted Koji Sauce (Mole)

750g Roasted Koji
1000g Cream
600g Milk

Roasted Koji

Break the Koji down into small as possible pieces and roast it 160°C. Turn or shake the koji every 10 min to get an even roast on it. After approximately 1 hour the Koji should smell a bit like roasted coffee and also should have the colour of it.

After it's cooled down, combine 750g roasted Koji with 1 liter of cream in a vacuum bag it and allow to infuse overnight in the fridge. Once rehydrated, add 600g of milk and blitz in a Thermomix on 70°C to a paste consistency. Pass it through a sauce net while still warm. Place into vacuum bags when cool and store frozen.

Koji Salt

300g fresh koji
300g salt
300g water

Blitz the ingredients in a blender and reserve in the fridge. This is an excellent cure for meats, particularly game birds.

Misos, Shoyus and Garums

Koji can also be used as a component in more complex fermentations involving different proteins. *Misos* and *Shoyus* (chapter 6) at noma involve koji and legumes, nuts, grains, leftover vegetables, seeds, or coffee ; *Garums* (chapter 7) involve animal proteins.

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Chapter Six

Miso and Shoyu

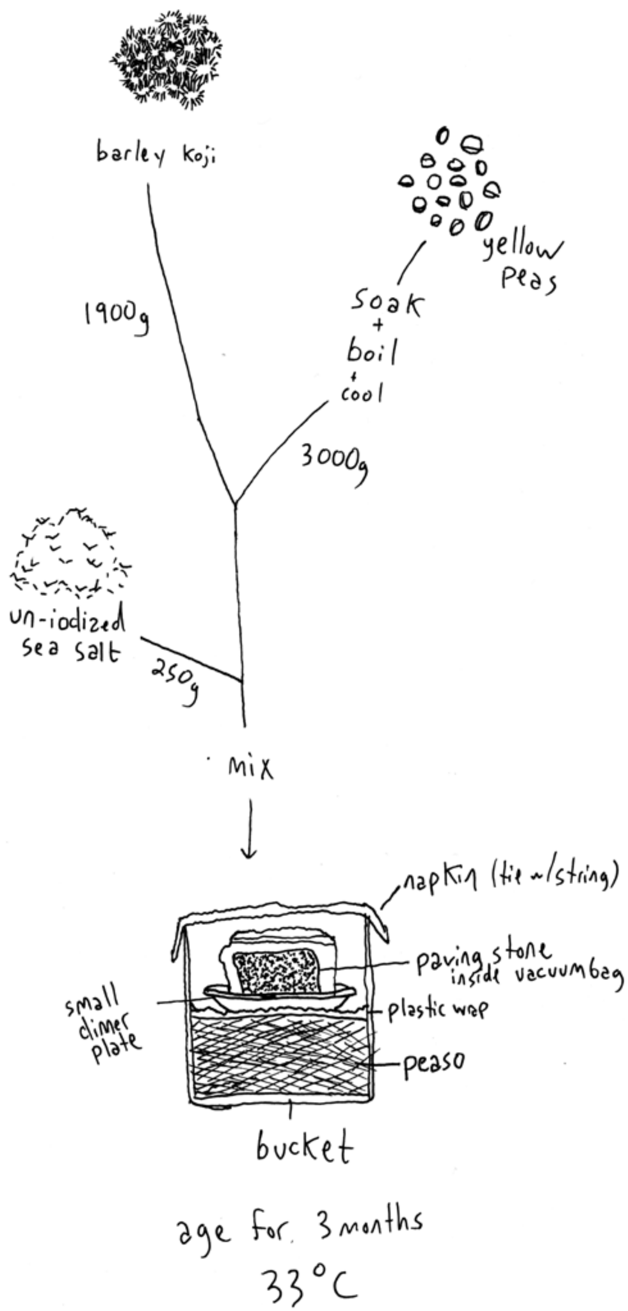
Nuts, legumes, grains, or other plant material fermented and aged with koji and salt

Process:

Koji enzymes break down starches in legumes into sugars, which are fermented by lactic bacteria, yeasts, and acetic bacteria; proteins are broken into umami flavors

Necessary components:

Koji; yellow peas, nuts, or bread; salt; bucket; rock



Basic Recipe: Pea-so (Yellow Pea Miso)

3000g Cooked Yellow Peas
1900g Inoculated Barley Koji
200g Fine Salt

Soak approximately 2000g dried yellow peas in cold water overnight. Strain and wash. Weigh the peas—they will increase by roughly 50% in weight. Seal 3000g of the soaked peas in a vacuum bag with 1000g of water and cook in a steam oven at 100°C for 2 hours. Cool down to room temperature. Strain the peas and reserve the cooking water.

Mix 3000g of cooked yellow peas and 1900g of finished Barley Koji (inoculated, molded pearl barley—see section 4 for more information).

IMPORTANT: *The moisture content of the mixture is extremely important, and will determine the success and flavor of the final product. Too much water will encourage an excessive activity in the onset of the fermentation, leading to an aggressive acidity or sharpness. Too little water and very little will happen. Take a small amount in your hand and clench your fist—the substrate should form a dense, bound paste. If a little sort of oozes between your fingers it is too wet, and if it remains crumbly, it is too dry.*

When the yellow pea-koji mixture is the correct consistency, weigh it and add 4% of that weight in fine, non-iodized salt. For this recipe that will be approximately 200g. Mix it well to make sure it is homogenous, and put the mixture into a 12L nonreactive container, taking care that there are no air pockets.

Cover the surface with cling film, ensuring the surface is not exposed to air. Place a plate on top of the clingfilm and load with 5 kg of weight (a clean paving stone in a vacuum bag, or a 5L container of water are ideal). Cover the container with a cloth to prevent contamination from flies, etc., and secure the cloth with a rubber band or string. Age the pea-so for at least 3 months, and up to 6 months, at an ambient temperature of 25-33°C. The aged pea-so should be lightly acidic but not overly sour.

The pea-so can be frozen at this point, or cooked off and passed before using in dishes or further storage.

If not being frozen, the peaso should be cooked off and passed before using in dishes or further storage.

Pea-so Notes

Why peas and why koji?
What you're doing here is using the enzymes created by *Aspergillus oryzae* (when it fermented the barley into koji) to break down the starches and proteins in another legume or grain, in this case yellow peas, to flavorful and fermentable components. Koji is needed to supply these enzymes, and yellow peas are the protein source.

Why 4% salt?
To age at room temperature safely and develop good flavors, salt is needed to impede spoilage bacteria and encourage lactic acid bacteria to grow. Generally, the longer the miso is going to age, the more salt you need to add (or, the more salt you add, the longer it needs to ferment).

Why weight the pea-so?
Weighting the pea-so helps prevent air pockets, and pushes excess liquid to the surface. It also keeps most of the pea-so surface out of contact with air, while letting it breathe and off-gas as needed. The weight placed on the pea-so should be approximately equal to the weight of the miso.

Why not just vacuum-seal the pea-so?
Completely sealing the miso will keep it out of contact with oxygen. But we want a little bit of contact with the air to let off any gaseous products of the fermentation and break down/oxidize some of the mid-fermentation aromas which can smell somewhat like nail polish remover. The pea-so is undergoing lactic, yeast, and acetic fermentations as it ages, and being under a cloth, plate, and plastic wrap instead of a hard seal helps stop it from getting too yeasty or boozy.

Why cook off or freeze the pea-so?
Cooking will kill off all the microbes in the pea-so, as well as denaturing (basically, breaking) the enzymes present. Skipping this step means the fermentation will keep going as the pea-so is stored, altering its flavor. Freezing will also radically slow the fermentation and aging process. Cooking off the pea-so also remediates any off-flavors, like the aforementioned nail polish remover smell, that sometimes develop during the fermentation, especially if you made the pea-so on the wetter side.

Why use yellow peas in particular?
When we began looking into making a miso-style fermentation, but with Nordic ingredients, it was necessary to find an analogue to soybeans, which are in no way Nordic. The point of making a miso is to develop umami flavors by breaking down proteins in an unfermented ingredient with the enzymes developed by the molded barley koji, so we needed something that was high in protein. Fortunately the Danish Technical University (DTU) publishes information about the nutritional breakdown of various Danish food plants; on their website we found that yellow peas have a particularly high amount of protein, so we made a "pea-so" out of yellow peas that turned out to be very tasty.

Miso Style Trouble-Shooting

The miso is bubbling:
This is normal, especially at the beginning of the fermentation.

The miso is quite boozy and sweet and has a Hefeweizen-banana smell:
You are at the yeast-growing phase of the miso fermentation; if you want it to be quite sour and have more umami flavor, you need to let it continue going for a while longer, so that the acetic and lactic fermentations can happen, and the proteases in the koji (which act more slowly) can do their thing.

There is some white mold on the surface or around the edges of the miso:
This is fairly normal. To stop lots and lots of mold from forming you can (lightly!) sprinkle non-iodized salt over the surface of the miso before you put plastic wrap and a plate on top of it.

The miso smells like nail polish-remover:
Fermenting miso is a balance between too much air circulation, which allows not-so-good molds to grow, and not enough. If you don't have enough air circulation and off-gassing, odd flavors can build up. So make sure you haven't sealed off your miso completely with plastic, and don't try to ferment it in a vacuum bag.

The miso smells like blue cheese, or like rancid fats:
These are the flavors that happen from fats, especially milk fats, breaking down enzymatically yielding blue cheese flavors, or from unsaturated nut fats oxidizing and yielding rancid, paintlike flavors. If you can press or spin out the fats from your substrate, you'll avoid these flavors.

The miso has just become very acidic very quickly:
This is often an issue of excess circulation, where there has been too much air and water available for the yeast and acidic bacteria, and they have propagated at a higher than desired rate. Too much liquid in the mix and/or not enough weight pressing evenly on the miso can also cause this.

Miso Variations

Rye-so (Rye Bread Miso)
Take 3000g of Danish Rye Bread, and blitz to a crumble. Add 2000g of blitzed koji, and mix in water until a proper firm-paste consistency is achieved. (This may be almost 2L) Calculate 4% of total weight (allowing for the salt in the Rye Bread, which in our case is 1.7%) and add this amount of fine non-iodized salt, and incorporate thoroughly in a nonreactive container. Cover the surface with clingfilm, a plate, and a weight as above for pea-so, and age for at least 3-6 weeks.

Nut Miso (Hazel-so, Wal-so, Pumpkin-so)
Take 3000g dry nut pulp (leftover from making nut oil) and 2000g of blitzed koji, and mix in water until a proper firm-paste consistency is achieved. (This may be almost 2L) Calculate 4% of total weight and add this amount of fine non-iodized salt, and incorporate thoroughly in a nonreactive container. Cover the surface with clingfilm, a plate, and a weight as above for pea-so, and age for at least 3-6 weeks (start tasting after 10 days). The nut miso are especially sensitive to excess water content, and will be very sour if too much is added, so it's better to err on the side of dry. If after 10 days the mixture is still too dry, compact, and sandy textured, mix in a small amount of water with 4% salt dissolved in it until it has more of a paste-like consistency.

Flavored Pea-so (here we often use byproducts from other processes)

3000g Cooked Yellow Peas
1900g Inoculated Barley Koji
500g Elderflower, Wild Rose, Thyme, etc. (We use the leftover pulp from oil production for this) If using fresh pine, limit to 5% (250g here)
200g Fine Salt

Combine and ferment as for Pea-so recipe.

Bread-so

2000g Bread Koji
3000g Toasted Bread
Filtered Water for consistency
4% Salt of above weight

First, make bread koji: take leftover sourdough bread, remove crust, and cut into a rough macedoine. Lightly dust with *Aspergillus oryzae* spores and place in a suitable environment for mold growth (see Koji section for more detailed instructions)

Take another batch of leftover bread, toast to a golden brown and blitz to a crumble. Mix with the finished Bread Koji, add water just until a firm paste is achieved. Calculate 4% salt, and incorporate with a large stick blender. Press firmly into a suitable container, cover surface with clingfilm, and load with 5kg of weight.

Vegetable Shoyu

1000g Vegetable (pumpkin scrap leftover from juicing for pumpkin shoyu, or cabbage juice from leftover cooked cabbages for cabbage shoyu)
100g Koji
44g Salt

Blend well, put in a bucket, cover with clingfilm, and age at 60C for 3 weeks. Strain and use the liquid.

Coffee Shoyu

4000g Koji
1000g Spent Coffee Grounds (after brewing coffee)
5000g Filtered Water
200g Salt

Blend well and age at 60°C for 4-6 weeks. Strain and use the liquid.

Dryad's Saddle Shoyu

1000g Dryad's Saddle Mushroom, blended to a paste
200g Koji
300g Filtered Water
60g Salt

Incorporate all the ingredients with a large stick blender. Place in a suitable container with the surface covered with clingfilm. Age at 33°C for 6 weeks. Press through a superbag.

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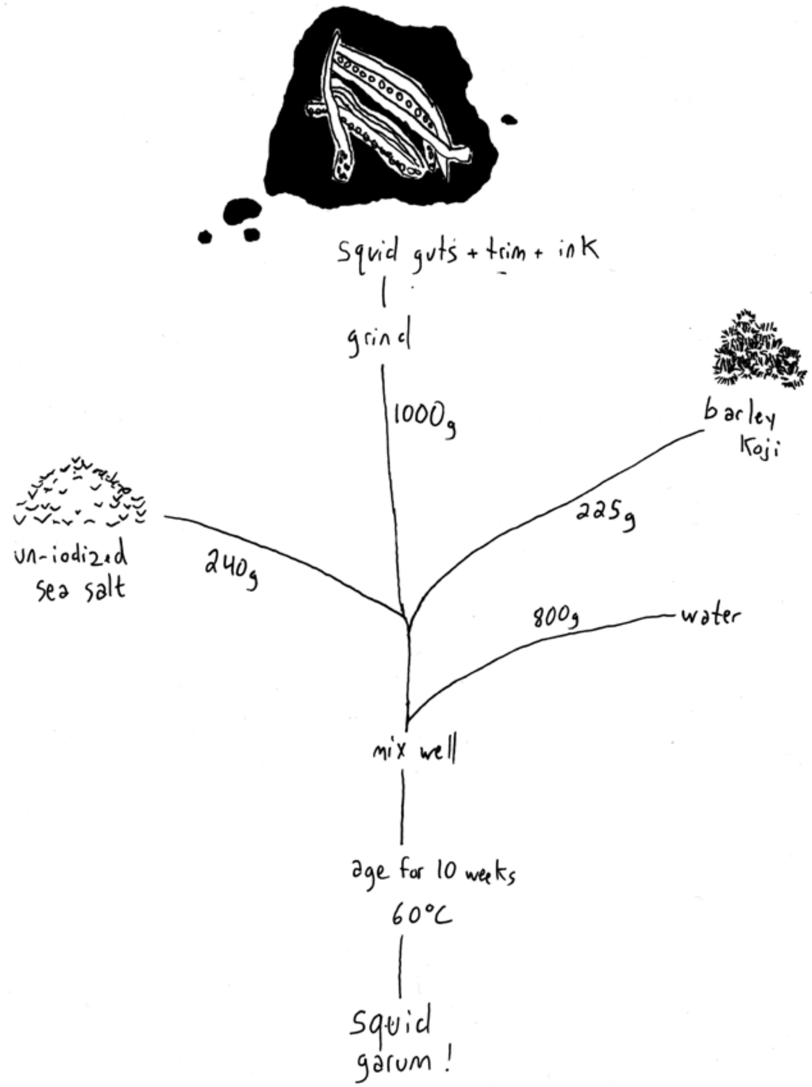
Chapter Seven

Garum

Animal proteins, aged with koji and salt

Process:
Controlled enzymatic breakdown of animal proteins by koji in a highly salty environment

Necessary components:
Koji, animal protein, salt



Basic Recipe: Grasshopper Garum (Fermented Grasshopper and Koji Sauce)

1000g Protein
225g Barley Koji
300g Filtered Water
240g Fine Salt

Blend 600g of wax moth larvae (they come frozen, in boxes) and 400g of grasshoppers well in a thermomix or blender to make a paste.

Incorporate the grasshopper and larvae paste with 240g of fine salt, 300g of filtered water, and 225g of finished barley koji in a non-reactive container.

Press plastic wrap onto the surface of the garum to keep it out of direct contact with the air. Incubate the garum at 60°C for 10 weeks. A PID box with heating and a temperature sensor is useful for this (see Appendix B for more details).

The mixture will separate into liquid at the bottom and solids at the top. The liquid (garum) will be a golden brown, and the solids a lighter orangey-brown. The garum should smell meaty, toasty, and slightly cheesy (like parmesan, not like blue cheese, camembert, or tallegio).

Decant the liquid at the bottom with a pipette or siphon, then blitz and pass the solids through a fine sauce net before use.

Garum Notes

What is going on in this recipe?
You're breaking down the proteins in the insects into delicious free amino acids (what are very umami) and other tasty flavors, and controlling this breakdown/slow rot with high levels of salt.

Why grasshoppers and wax moth larvae?
Insects contain high levels of protein, which on its own doesn't have a lot of flavor. But, when these proteins are broken down into amino acids by the proteolytic enzymes (proteases) in the koji, rich umami taste develops as well as other toasty and cheesy flavors.

Why salt?
For grasshopper garum you add about 11% salt, which is 3 times as much as for misos. This percentage of salt will slow most microbial activity, including lactic acid bacteria, to the point where garum won't develop much acidity and is instead more of a controlled rot/enzymatic breakdown of the meat and larvae proteins.

Why Koji?
Koji has a lot of enzymes in it that are good at breaking down proteins, which helps speed up the process of producing garum; this speeded-up breakdown also allows for the use of less salt for a more versatile sauce.

Why hold at 60°C?
Heating up the garum helps it break down the meat protein faster, and at 60°C the umami flavor and caramelized flavors are most emphasized; at higher temperatures it will ferment faster but can taste over-browned.

Why do you call it garum?
Garum was one of the most popular sauces in the ancient Roman era, and was made much like Thai or Vietnamese fish sauces are today, with the flesh and guts of small fish and lots of salt left to ferment and break down over time. We add koji instead of fish guts to supply the protein-digesting enzymes, but the process is similar. The garums we produce at noma are also similar in process to the chiang and miso produced in ancient China and Japan from rice qu/koji, meats, and salt before soybeans were widely used.

Garum Trouble-Shooting

This just seems very sketchy.
Actually the garums are the safest, simplest and easiest of the ferments to control. The high heat, and relatively high salt content protect them from the great majority of unwanted microbes.

The fish/shellfish garum smells....really dodgy.
Sorry. It always does in the beginning. This is normal. Man the fuck up. But if after a while it smells like the ocean took a dump on a dead whale, you should start with fresher fish/squid/etc next time.

So....I left it alone like you said, and it's gone from really dodgy-fishmarket to pure death-smell.
It cannot be reiterated enough that the product must be extremely fresh. This process is not for the things you forgot about in the fridge and that already smell like a street urchin with the black plague. If it's not fresh enough to eat, it's not fresh enough to preserve.

Garum Variations

Beef Garum

600g Beef, ground
400g wax moth larvae
800g filtered water
240g salt

Blend 400g wax moth larvae in a blender or Thermomix until smooth.

Mix this puree by hand with 600g of raw beef trim or ground beef, 225g barley koji, 800g filtered water, and 240g of salt until well-combined.

Cover, ferment, and process as for grasshopper garum, above.

Squid Garum

1000g Squid Trim
225g barley koji
800g water
240g fine salt

Grind the koji, water, salt, and squid trim (guts, ink, tentacles, everything except the clear pen or gladius) into a rough puree using a Thermomix, robot coupe, or meat grinder.

Cover and ferment as for grasshopper garum, above.

This recipe works well with any kind of very fresh shellfish trim. Lobster bodies, mahogany or razor clam scraps, the goop leftover from cleaning sea urchins—these have all made fantastic garums.

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Epilogue

Fermentation...

Some time ago we were showing a pair of chefs from a two star restaurant around our fermentation kitchen, going through the different processes, and the multiple applications they are associated with. After about thirty minutes or so of careful, attentive nods of comprehension the senior of the two interrupted me, his brow furrowed. "So—is that fermentation?" pointing at the vinegar room, "Or is that?" gesturing to the steam filled chamber of 'koji.' Despite my efforts to the contrary, everything had remained a mystery, a hall of smoke and mirrors. Some of the cooks at our restaurant have a similarly vague grasp of what methods lead to which results, only aware that products go over to the lab to be put into buckets or bags, and after some period of time come back tasting remarkably different.

It is important to remember that fermentation is cooking. There are different tools, different timeframes, perhaps a new skill set to learn, but nothing more dramatic than learning to make sauces, work a grill, or proper butchery. Common sense and curiosity must balance each other, as always. "How dangerous is all this?" is a common question we field from guests. The answer is that it's no more dangerous than cooking anything else. If a person cooks fish they should know how to tell if it is fresh enough to eat. The same is obvious for vegetables. Bread, wine, and beer are often made by home cooks with impunity, because these fermentations are part of our culture. The methods outlined here only require the same care and attention that would be a part of any cookery.

This Field Guide is only intended to be a primer to the processes of fermentation, a framework to build upon. The hope is that by sharing a few successes and a lot of failures, we can further a collaboration in the greater community, where we might all benefit from each other's work. The ingredients we have used here are merely the ones we find around us—if pistachios grow in your part of the world, make a miso out of those, or if you come across sumac in your landscape, that would be ideal for a kombucha.

The greatest successes often seem obvious in hindsight, and may come upon one with a resounding slap of the forehead, or in complete serendipity. The Hazel-So of which we are currently fond was borne on both: we had struggled to make a sufficiently umami-rich and flavorsome hazelnut miso-style ferment because of the high amount of oil in the nuts which would impart a distinct rancidity after a week or so. Some time later, we began to press our own oils, mostly hazelnut, and after binning the dry and somewhat tasteless left-overs from the nut press we had one of those head-slapping moments— this 'garbage' (which of course was only that because of the way we thought of it) was exactly what we had needed for the miso-style ferment. All of the hazelnut besides the oil. So now we occasionally find ourselves pressing oil just to have the 'garbage' left-overs for making the Hazel-so.

The Squid Garum was similar in a way; laden with the knowledge of how garums were historically made from the innards of Mediterranean fish, it still somehow took us a while to make the cognitive leap to the guts of the squid we had been throwing in the bin. Now we make a range of delicious fermented sauces from every scrap of shellfish and meat that gets processed by the restaurant.

In the end, this 'head-slapping,' however frustrating, should be seen with optimism—it indicates that, despite working on these things for several years, we are only scratching at the surface, with a wealth of discoveries waiting to be stumbled upon. In finding these there will of course be questions, unknowns, wandering off the common path and forays into dead ends and unexplored territory. Many things you may try might not be easily Googleable, might require trolling through patents and academic papers to get an opaque suggestion about what you should be doing, but that's the whole point. We attempt to retain our skillset while discarding our biases and routines. It is always the lines we cannot see, our preconceptions, that are the hardest to cross.

There are steps you can take to ensure that you're not setting yourself up for failure. Cleanliness, sanitation, and exhaustive tasting as each process evolves are paramount. Flavor dominates, and flavor is the strongest tool you have to tell you if everything is working as it should. Of course, each of these techniques is only as good as the ingredients you put into them; lacto-fermenting shit quality cherries only leads to shitty lacto-fermented cherries. Lacto-fermenting beautiful wild cherries in their prime will allow the sublime to emerge. The same is true for Squid Garum—it is a technique that transforms a waste product into something really special, but it can't save bad fish; good Squid Garum comes from product that is good, fresh, and high quality to begin with. Perhaps the most critical thing to remember is that nature will not be denied; life finds a way. Something is going to grow. The best bet is to provide an advantage at the outset for the species that you would like to win.

We established a Fermentation Kitchen at our restaurant as we began to incorporate these techniques into our entire menu, from the first bite to the desserts and petits fours, and as we expanded the techniques we have used for many years. Now practically every ingredient, whether oil, vinegar, spice, or umami rich paste, is painstakingly produced at the restaurant, which gives us certain flavors that cannot be reproduced elsewhere—beautiful local produce transformed by the microbes around them, a logical extension of time and place as seen through the paradigm of deliciousness. If one were to bring Copenhagen ryebread to New York, and make Rye-so there, it would taste different, due to the local microbes. There is a palpable joy in tasting something new, and traveling to savour something which tastes of its place, its landscape.

But there is an even greater joy in creating or discovering a new flavour, and we hope that you will not only try to replicate the recipes here, but embark on your own explorations, so that we in turn may be inspired.

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Appendix A

Control and Safety with Fermentations

“Controlling” a fermentation means making sure only the microbes you want to grow are growing, and that they're producing optimal flavors.

The basic methods for controllingways you control a fermentation are through salt, pH/acidity, water activity, oxygen levels, temperature, food/energy source/substrate, and inoculation. Necessary controls for each type of fermentation are included in specific recipes; this is a more general discussion about what these controls are and how they work.

For any of these fermentations, a clean workspace, clean hands, and washing your ingredients are the most basic safety parameters you can follow, as is being sure to throw away anything you feel unsure about or that smells “off.”

A note on botulism

Botulism is a very rare but potentially fatal paralytic illness caused by botulinumm toxin, a neurotoxin produced by the bacterium *Clostridium botulinum*. The reason you should care about it is that, unlike most other forms of spoilage, it is not detectable by smell. *C. botulinum* requires a protein source, a relatively warm temperature, and a completely anaerobic, low-salt, low-acid, low-sugar environment to grow. For this reason it tends to grow in improperly canned meat and improperly preserved fish. Acidity levels below pH 4.6, or salt levels above 7%, are each able to protect from botulism. Salty, acidic foods that have lactic bacteria growing in them are even safer. So, for protein-rich fermentations, rapid acidification and sufficient levels of salt, as well as avoiding a completely oxygen-free environment, are all essential for safety. This doesn't mean you should be afraid of them, but that you should be especially cautious about doing these fermentations properly.

Salt

If you're doing lacto-fermentation (e.g. lacto plums) or fermenting anything with koji (koji water, miso, shoyu, garum) you're going to be using salt.

Lactic acid bacteria (LAB) are able to tolerate salt concentrations that most yeasts, molds, and other bacteria can't grow in, so salting is an effective way to control what types of microorganisms can grow. We use salt concentration ranges between 2% and 4% to suppress spoilage bacteria and molds and let lactic acid bacteria proliferate and produce an acidic environment. We use higher salt levels, around 11%, to suppress LAB along with other microbes and enzymatically ferment and break down animal proteins in a controlled manner for garums. For anything that's not acidic (below pH 4.6), and not going to become acidifed by lactic or acetic bacteria (for example, garums) salt levels well above 7% should always be used to ensure safety from dangerous microbes like *Clostridium botulinum*.

Acidity and pH

Acidity inhibits the growth of molds and other spoilage microorganisms. Lactic and acetic bacteria both produce acidity as they ferment, which helps preserve the products we make with them—lactic fermentations, vinegars, shoyu, miso—and also makes them taste sour. Acidity is manipulated in vinegars and kombuchas, and created in the course of these and lactic fermentations, as well as in shoyus and misos

Acids taste sour—lactic acid, acetic acid, citric acid, ascorbic acid (vitamin C), and malic acid are all organic acids which may be familiar to you. Most fruits produce varied ratios of citric, malic, and ascorbic acid. Lactic acid is produced by lactic acid bacteria as a by-product of their use of sugar as fuel; acetic acid is a similar by-product of the metabolism of acetic bacteria fueled by ethyl alcohol.

Molecules which create acidity and have a sour taste do so because when dissolved in water, a hydrogen ion (or several hydrogens in some cases) detaches itself from the main body of the molecule. The more hydrogen ions that are dissolved in a solution, the more acidic it is and the more sour it tastes.

pH is a measure of acidity; somewhat confusingly, pH is a reverse scale, which means that the lower the pH, the higher the level of acid (measured as hydrogen ions) present. A pH of 7 is completely neutral; below 7 is acidic and above 7 is alkaline/basic.

Higher levels of acidity (or lower pH levels) create less hospitable environments for the microbes that would ruin a fermentation or render it unsafe—including many molds, Clostridium botulinum (the bacteria responsible for botulism), and other spoilage and pathogenic organisms.

Generally, the rule of thumb where foods are safe is pH 4.6—at or below this level, there is enough acidity to halt the growth of dangerous microorganisms like Clostridium botulinum, which can grow in low-acid, low-salt, low-sugar, low-oxygen environments.

(It's also possible to use high alkalinity to preserve foods; Chinese century eggs, which are cured in lye, are one example of this. We don't really have a dedicated taste receptor for alkalinity the way we do for acidity so alkaline foods tend to taste slightly bitter or soapy).

In aerobic conditions, a low pH can help stop the growth of undesirable surface molds that would cause spoilage.

Oxygen

Certain processes like mold growth and acetic fermentation, can only happen in the presence of oxygen, so when we would prefer these not to occur, we remove oxygen from the fermentation environment by sealing in a vacuum bag or with an airlock. When we do want them to happen, like to make koji or vinegar, we make sure that a lot of oxygen is available.

Microbes and the fermentation processes they perform can generally be divided into those requiring oxygen (aerobic) and those which require or prefer the absence of oxygen (anaerobic). Yeasts and lactic acid bacteria both perform fermentations without oxygen (recall that these follow the strict biochemical definition of fermentation). Acetic bacteria and Aspergillus oryzae both require oxygen to make vinegar and koji, respectively.

Temperature

Controlling temperature lets you control the speed at which you're fermenting and the growth of different types of microbes, both of which are important for safety and flavor. You can manipulate temperature to make the things you want to grow, grow very fast; or amp up the activity of different enzymes which can speed up flavor development (we heat misos to 33-35°C and Garums to 50-60°C to boost amylase and protease activity). You can also slow down things you don't want to grow and prevent off-flavors—lacto-fermentations of fruits and vegetables are kept at a lower temperature than misos to slow yeast growth, for example. See the section on temperature control later in the book for examples of target ranges.

Substrate

You can think of using substrate (the ingredient or material you're fermenting) to control the fermentation process in two ways:

1. Deciding on a product you want to end up with, like lacto-fermented berries, kombucha, or garum, and then picking a substrate that has the right composition to make that product, like berries, something that can be made into tea, or something to grow the koji and a tasty fresh animal protein.

2. You have a lot of ingredient X (for example, clam guts) and want to ferment it. Based on your understanding of the composition of ingredient X and how different fermentation processes work, you can figure out what you need to add or do to make these act effectively on it, or what is the ideal fermentation to use with it (in the case of clam guts, probably a garum.)

Understanding the relationships between substrate composition and microbe happiness is probably the most important tool for experimenting with fermentation successfully. This lets you know what you CAN do based on what you have, and what's likely to be a nonstarter. This isn't to say that you shouldn't experiment and take a chance on something which might not work—but that knowing the basics will make your experimentation smarter, faster, and more delicious.

Some of these substrate basics:

- if there are no sugars, it won't lacto-ferment.
- if you don't have any alcohol, you can't make vinegar.
- *Aspergillus oryzae* can thrive on starches, but not so well on cellulose. Cellulose is made out of linked glucose molecules but has different linkages that the amylase enzymes in starches aren't able to chomp on. So koji will grow rather poorly on unstarchy vegetable matter.
- misos and garums develop flavor by breaking down starches and proteins into small building blocks—flavor comes from these building blocks (sugars and amino acids) and the things they break down and are transformed into (see pages 9-15 on the flavors of fermentation.) So the thing you're trying to make into miso should have starch and protein in it if you want it to taste good.

This book is just a guide—something that seemingly has the right characteristics for a fermentation might not actually work very well, but it's difficult to know until you experiment. Different grains, for example, have the starchiness and protein content that should make excellent koji, but their husks or the way they take up and hold water might mean that the cooking technique you use for pearl barley doesn't work for, say, quinoa or buckwheat. It might take several tries to get something new to work.

Inoculation

Some fermentations will proceed quite happily from microbes that are hanging around in the environment—this is how we do lactic fermentations, and it's the basis for natural winemaking. In other situations, it is useful in the beginning to add a dose of the microbes you want to be the dominant actors in your fermentation, so you can make sure that they outcompete less desirable or dangerous strains.

This is especially important in dicier conditions where the microbes that grow spontaneously may have nasty side effects; if you're making conditions to intentionally encourage mold growth, you want to make sure the right kind of mold is growing.

Some fermentations won't proceed at all without inoculation. The community of yeasts and bacteria that transforms sweetened tea into kombucha doesn't really exist or hang around in the wild—it needs to be inoculated by transferring a community from old kombucha to new kombucha.

Things you definitely want to inoculate:
Koji, kombucha

Things we generally inoculate but can also grow spontaneously:
Alcoholic yeast fermentations, acetic fermentations

Things we don't generally inoculate because we get more interesting flavors without inoculation, (but control what microbes can grow via the preceding methods):
Lactofermentations, misos, shoyus, garums.

Baker's Percentages for Fermentation

Congratulations! You read all the recipes and understand how they work. If you have an odd amount of a base ingredient and know how to use baker's percentages you can scale each recipe to any weight using the proportions below.

Recipe	Base		Calculate and Add	
Lacto-fermentation	Fruit, Ceps	100%	Salt	2%
Kombucha (Tea)	Tea	100%	Sugar	12%
			Old Kombucha	10%
Kombucha (Juice)	Juice	100%	Old Kombucha	10%
Vinegar	Juice	100%	Apple Vinegar	20%
			High-Proof Alcohol	9.60%
Pea-so	Cooked yellow peas and some of their cooking water*	100%	Barley Koji	64%
			Salt**	8.30%
Rye-so/Nut-so	Rye Bread, Nuts, Seeds, etc	100%	Barley Koji	67%
			Water*	83%
			Salt**	6.50%
Vegetable Shoyu	Vegetable Pulp	100%	Koji	10%
			Salt	4%
Coffee Shoyu	Coffee Grounds	100%	Koji	400%
			Water	500%
			Salt	20%
Garum	VERY fresh squid trim, clam scraps, grasshoppers+ grubs, etc	100%	Koji	22.5%
			Water	80%
			Salt	24%

* Water additions for peaso, rye-so, nuts-so, etc. are best done by feel- these are just a guideline.
** For these recipes, it's better to NOT use a baker's percentage, add water by feel, and THEN add salt based on the final weight of base, koji, and water.

Overall Ingredient Percentages in Each Recipe

Recipe	Base		Additional Ingredients	
Lacto-fermentation	Fruit, Ceps	98%	Salt	2%
Kombucha (Tea)	Tea	82%	Sugar	10%
			Old Kombucha	8%
Kombucha (Juice)	Juice	91%	Old Kombucha	9%
Vinegar	Juice	77%	Apple Vinegar	15%
			High-Proof Alcohol	8%
Pea-so	Cooked yellow peas and some of their cooking water*	58%	Barley Koji	38%
			Salt**	4%
Rye-so/Nut-so	Rye Bread, Nuts, Seeds, etc	38%	Barley Koji	26%
			Water*	32%
			Salt**	4%
Vegetable Shoyu	Vegetable Pulp	87%	Koji	9%
			Salt	4%
Coffee Shoyu	Coffee Grounds	10%	Koji	39%
			Water	49%
			Salt	2%
Garum	VERY fresh squid trim, clam scraps, grasshoppers+ grubs, etc	44%	Koji	10%
			Water	35%
			Salt	11%

* Water percentage approximate—water should be added to these recipes according to feel.
** For these recipes, calculate salt addition last, AFTER water additon.

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Appendix B

The Tools of Fermentation

Oxygen control: vacuum bags, buckets, cloth lids, airlocks, and bubblers

As you may have gathered in reading sections on specific fermentations, controlling exposure to oxygen (removing it or encouraging it) is an important factor for doing a successful fermentation. Lactic and yeast fermentations should be protected from oxygen; miso and garum fermentations shouldn't be left open to the atmosphere but shouldn't be totally oxygen-free (anaerobic), and vinegar, kombucha, and koji fermentations need a plentiful supply of oxygen.

The tools we use for controlling exposure to oxygen for each fermentation are mentioned in their respective chapters. Here they will be discussed in more detail.

Oxygen exclusion: vacuum bags and airlocks

A good way to prevent oxygen from reaching a fermentation is by removing it and then sealing the fermenting mixture. This is what we do with lactic fermentations, which are sealed with salt in a vacuum bag until the fermentation is done. At this point, the bag will have swelled up with carbon dioxide gas, which is a byproduct of the fermentation process. This illustrates one limitation of vacuum bags: they are good at keeping what's in them contained, but they aren't good at letting gas out.

For fermentations that produce a very large amount of carbon dioxide, such as alcoholic fermentations with yeast—which usually involve more sugar and therefore more carbon dioxide—a device called an airlock is especially useful. An airlock is a small, usually plastic device that is filled with water and seals a small opening in a bucket or jug holding a fermentation. As carbon dioxide builds up, it increases in pressure, which is released by bubbling through the water in the airlock. The atmosphere on the other side can't push its way into the container through the water because it's at a lower pressure. So, oxygen-rich atmospheric air is kept out, carbon dioxide can be released, and the fermentation keeps going without mold growth or oxidation.

Passive barriers: clingfilm hats and cloth lids

For miso and garum fermentations, it's useful to protect the surface of the product from direct air contact, which can lead to mold growth. However, better flavor results if the fermenting mixture is not completely sealed off from air. Some of the fermentation processes seem to perform better if they're not strictly anaerobic. Letting in some air also improves the flavor and prevents solvent or nail-polish-like off-flavors, either by breaking down the ethyl acetate that is responsible or letting it off-gas. For both of these we press clingfilm onto the surface of the miso or garum as a kind of "hat," but leave the edges loose.

Any fermentation that gets airflow from the atmosphere needs to be protected from fruit flies and errant mold spores by some kind of air-permeable lid. We cover misos, garums, kombuchas, and vinegar fermentations with a cloth secured by a rubber band or string.

Active oxygenation: bubblers

Acetic bacteria require oxygen to ferment alcohol into vinegar, and will grow and ferment faster if they are supplied with lots of oxygen. To make a vinegar quickly, we circulate air into the fermentation. For volumes between 3-10 L, we usually use an aquarium air pump and an airstone, which we buy from a pet store. These airstones use a pump to forces atmospheric air down a tube and through a porous stone, which makes tiny bubbles of the air and increases the surface area exposed to oxygen of the liquid in which they are submerged. For larger amounts of vinegar (up to 18 L), we use a dedicated vinegar machine (which would be used for very small test batches in a commercial vinegar brewery) which aerates the vinegar by forcing it through a small aperture called a venturi aspirator, which effectively increases the oxygen contact and fermentation speed of the vinegar mixture.

Humidity

Avoiding dry-out is generally more of an issue for fermentation and aging than removing humidity. For fermentation in a closed environment (like a wine fridge or disused freezer), keeping an open, full container of water near the heat source is usually good at maintaining humidity levels. If you have a dedicated room for growing koji or aging misos or garums, a domestic humidifier can work well for the same purpose. We have used both of these strategies effectively; in our current set-up we have a built-in humidification system that has a humidity sensor and an ultrasonic fogger, which monitors levels itself and doesn't need to be refilled but otherwise works like a fancy humidifier.

If you have the luxury of being able to set humidity levels, the ranges you want to aim for are:

Lactofermentation: 40-50% relative humidity
Kombucha: 50-60% relative humidity (to avoid excessive evaporation)
Vinegar: 50-60% relative humidity (to avoid excessive evaporation)
Koji: 80-90% relative humidity
Miso: 50-60% relative humidity (to avoid excessive evaporation)
Garum: 65-70% relative humidity (to avoid excessive evaporation)
Cured Meats: 70% relative humidity, with good air circulation

Temperature control: PID boxes and heating sources

Keeping a precise, level temperature is important for controlling the rate of a fermentation and what is growing in it, both of which have an important impact on flavor.

These are the working ranges for each of the processes in this book and others you might want to do:

Lactofermentation: 20-30 °C
Kombucha: 20-25°C
Vinegar: 25-30°C
Koji: 28-33°C
Miso: 28-33°C
Garum: 60°C
Yogurt and Creme Fraiche: 38-43°C
Cured Meats: 10-15°C
Sake: 10-15°C
Fruit Wines: 21-30°C if you're trying to extract color/tannins, 7-15°C for delicate, not very tannic ingredients
Beer: 17-25°C for ale, 8-14°C for lager (warmer = fruity, banana, buttery off-flavors)

Most of these temperatures fall somewhere in between refrigerator temperatures (1-5°C) and temperatures you can reliably set ovens to (40°C plus). Note that even though you can often set nicer combi ovens like a Rational to 30°C, the temperature will often spike a lot higher (40°C+) briefly during its heating cycle, which can kill off the microbes you're trying to cultivate at 30°C.

If you're going to get serious about doing these fermentations, you will have a much easier and better time with some kind of accurate heat control. For this, we highly recommend using a PID temperature controller to control your heat source. A PID box is connected to an electrical power source, a temperature sensor and a heat source. "PID" stands for "Proportional Integral Derivative" which means that the box uses calculus to figure out heating rate and heating output (based on the readings it gets from the temperature sensor) and sends a certain amount of current through the heat source to keep a very stable temperature. Auber, Brainchild, and Eurotherm all make good PID boxes.

For a heat source, you want something that can heat a fairly odd-shaped area pretty evenly. We have used heating blankets, seedling mats, and (most often) under-floor heating mesh for this. Under-floor heating mesh is sold in rolls to put down under a bathroom or other floor to heat it radiantly, and can be used to line a styrofoam thermal box, an unplugged chest freezer or refrigerator, or almost any other container. You could theoretically make individual jackets, each controlled by PID box, for fermentation containers out of this. The heating wires that make up the mesh tend to get quite hot to the touch, so while the heat will spread through the air pretty evenly they can melt or soften temperature-sensitive materials like soft plastic or styrofoam when in direct contact.

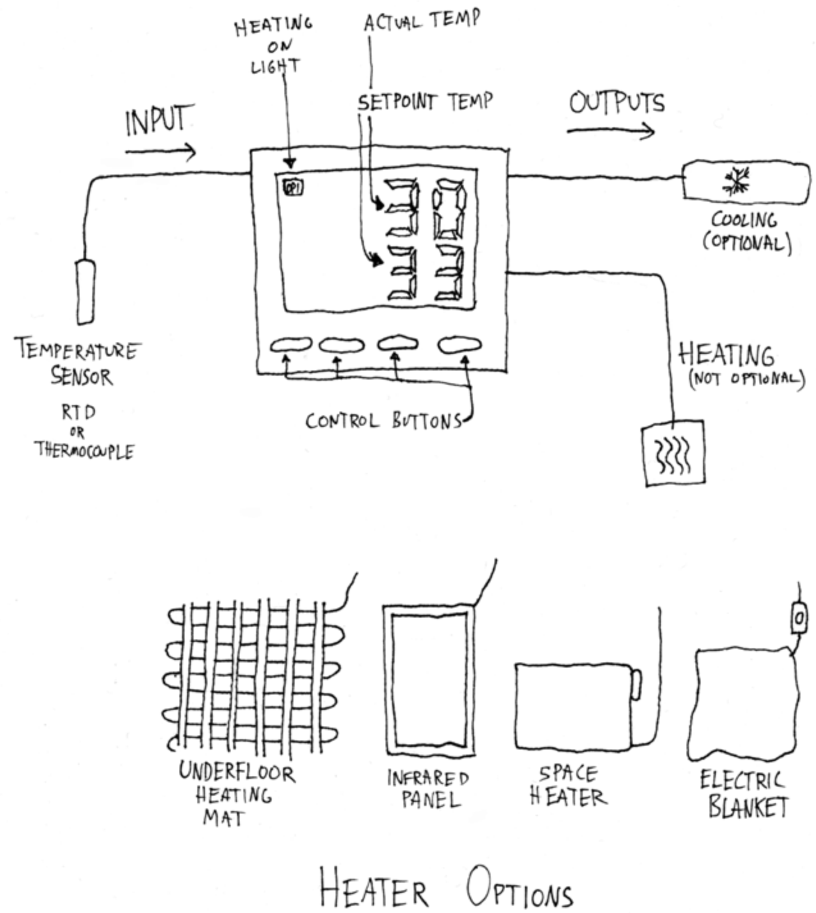
For larger rooms, we have had success wiring PID boxes to large infrared heating panels, which gently but effectively heat up an entire room. If they are ceiling-mounted and the flooring material is a dark material, this can cause heat to radiate from the floor and more evenly heat the room. Theoretically, a space heater could also be used to heat a room. Some PID boxes come with a standard plug-in connector for heating sources, but many need to be hard-wired (and floor heating mesh, wall mounted panels, etc. don't usually come wired with plugs).

K-type thermocouples and RTD sensors are the most accessible and easy to find if the PID controller you have doesn't come with a sensor. RTD sensors are more accurate and thermocouples have a much wider working temperature range and are easier to wire, but the wire is fairly expensive. (Besides fermentation, you can do cool things with a PID box like put the thermocouple sensor inside a Green Egg grill, and use a fan pointed at the coals as a "heat source" to keep the grill at a stable 1000°C for a long time. If you want to try anything very high-temperature, use a thermocouple).

Measuring sugar: refractometers and hydrometers

For kombucha and yeast fermentations, you will need to measure sugar to make sure it is within the correct range for the amount of acidity or alcohol you ultimately want to reach.

Glass Hydrometer: measures sugar by density. You fill a tall container (like a graduated cylinder) with the sample you want to measure, and gently drop the hydrometer, which is a long hollow glass piece with a wider, weighted bottom



PID box schematic

and a thinner top with a measurement scale printed inside. The hydrometer will float higher in a more sugary solution, which is denser, than in a less sugary solution, which is less dense. When it is floating evenly and not bobbing up and down, you can read the specific gravity (density compared to water) or Brix (% dissolved sugars) at the line where the handle of the hydrometer emerges from the solution. These are inexpensive and don't require calibration, but are easy to break and require large sample volumes to float in.

Refractometer: measures sugar by refraction, or how much it bends light that passes through it. One version is a totally analog model, where you put a few drops of sample on an angled glass plate, close a cover over it, then hold it up to the light and read the brix from a scale visible through an eyepiece. These are less expensive than a digital meter, but usually only read up to 30-35 Brix and can be annoying to train someone to use properly. A digital refractometer (the Hanna company makes good ones) can be had for about $170 in the US, and will read accurately up to 85 Brix. To operate these, you drip a small amount of sample on a ~8-mm wide glass plate and press a button; it measures the refractive index and displays a Brix value. If you're going to do a lot of measuring this is a worthwhile investment. An analog model is slightly lighter and more portable if you plan on taking it to a farm or something like that.

Measuring acidity: pH meters

pH is an essential measurement of acidity for making kombucha, vinegar, and miso. The simplest and cheapest method for this is pH paper, which turns different colors according to pH which are then matched to a reference chart. This is not a terribly precise method, but is useful for a quick check and doesn't require calibration, though the color the paper turnsbecomes can be affected by the color of the sample. A digital pH meter is a worthwhile investment, and a small pen-style model usually runs $40-100. It should occasionally be calibrated using standard solutions, which will most likely also be sold from wherever you bought your pH meter (Amazon.com, lab supply company, homebrewing and winemaking shops, for example). For measuring the pH of miso, you should get something called a double-junction probe, as a standard pH meter will get proteins stuck to it in a way that can't be cleaned.

If you need to take a lot of pH measurements, and especially if you need to record pH measurements, buying a digital pH meter that connects to the headphone jack of an iPhone/iPad is a good idea. We use a model called the SAM-1, which is produced by an American company called Sensorex. This runs about $200-250 for the iPhone adaptor and a spear-tip, double-junction (protein-safe) probe. This model can also email you a spreadsheet of readings from your phone.

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Glossary

acetic acid
The acid that makes vinegar sour, produced from ethyl alcohol by acetic acid bacteria.

amino acid
A building block for proteins, which are folded-up long chains of amino acids. One amino acid in particular, glutamic acid (also called glutamate), is responsible for the sensation of umami taste: the richness in kelp, aged meats and cheese, tomatoes, and miso. We do fermentations like miso or garum where proteins get broken down into amino acids to create this umami flavor.

amylase
An enzyme that breaks down starch molecules into sugar molecules. Amylases play a big role in fermentation, for example in the malting process for making beer from starchy barley grains, and in the process of growing koji from *Aspergillus oryzae* spores on barley or rice grains. They are a powerful tool for making unfermentable ingredients more fermentable—for example, in making miso, the sugars that are created initially by the amylase in koji can then be fermented by lactic acid bacteria and salt-tolerant yeasts, creating complex flavors and preservation that wouldn't have been possible without this initial starch-digesting (amylytic) step.

Aspergillus oryzae
A mold originally from East Asia, which we use to make koji. We use koji for making miso, garum, shoyu, and koji water. Aspergillus oryzae converts starches into sugars and proteins into amino acids as part of its growth process and metabolism, and we take advantage of this and use koji to intentionally ferment carbohydrate- and protein-rich ingredients.

backslop
To inoculate a new fermentation by adding a finished, active fermentation to it. We make new vinegar by backslopping old vinegar into fresh, alcoholic liquid—the acetic bacteria living in the old vinegar grows in the new liquid and turns it all into vinegar. Some beer brewers will backslop yeast from a finished batch of beer into a new batch.

bacteria
Bacteria generally speaking are some of the oldest and most abundant organisms on earth, and unlike fungi and animal cells, are Prokaryotic (have no cell nuclei or other membrane-bound cell organelles), whereas fungi and animals are Eukaryotic (have their DNA inside nuclei, and specialized organelles inside the cell like the mitochondria, ribosomes, etc.) Bacteria we use for fermentation include lactic acid bacteria (LAB) and acetic acid bacteria (AAB). Both of these produce acids—LAB produce lactic acid from sugars, and AAAB produce acetic acid from alcohol. LAB are used to ferment sauerkraut, lacto fruits and mushrooms, koji water, and miso as well as yogurt, creme fraiche and cheese. AAB primarily ferment vinegar and kombucha and also create some acidity in misos. LAB can ferment and grow without oxygen (and many species prefer it) and AAB need oxygen to ferment and grow.

carbohydrate
A sugar or a molecule made of many sugar molecules linked together. Also called a saccharide— glucose is a monosaccharide, sucrose is a disaccharide, and starch and cellulose are polysaccharides.

enzyme
For the purposes of fermentation, an enzyme is a protein produced by a microbe to break down or chemically transform a molecule. For example, *Aspergillus oryzae* produces enzymes called proteases that break down a protein, which is a long chain of amino acids, into individual amino acids. Enzymes are usually named as "the thing they break down"+"ase" so, prote-ase breaks down proteins and amyl-ase breaks down starches (called "amylum" in Latin). More technically speaking, enzymes are produced in all living cells, and are the machinery that allows life to exist on a cellular level by catalyzing necessary bio-reactions that would otherwise happen very slowly or not at all.

ferment
Through fermentation we can make vinegar, kombucha, koji, miso, garum, sauerkraut, yogurt, beer, wine, and bread. We use "fermentation" generally to mean growing microbes in an ingredient and using their metabolic processes and enzymes to transform that ingredient. Very technically speaking, fermentation is also a metabolic process that releases energy from organic molecules (often, but not always, sugars) in the absence of oxygen.

fungus
The two fungi we use most often are Aspergillus oryzae (a mold, which converts starches into sugars and proteins into amino acids) for making koji, and Saccharomyces cerevisiae (a yeast, which converts sugars into ethyl alcohol) for making bread, wine, and beer. Mushrooms, molds, and yeasts are all types of fungus. Fungi can't photosynthesize their own food (as a plant would) and so they have to digest materials in their environment to get energy. To do this many of them produce enzymes which break down (technically speaking, they hydrolyze) molecules like starch, cellulose, and lignin.

garum
Historically, an ancient Greco-Roman condiment made from salted fish guts and innards allowed to ferment for months or years. The salt prevented the garum from spoiling, and the proteins in the fish were broken down by the proteases present in all cells and also in the fish's digestive tracts. We use the term garum to refer to any animal protein fermented enzymatically and with salt added, although we use the proteases in koji rather than in guts.

inoculate
You can kickstart a fermentation by adding a dose of the microbes you want to use at the beginning. Sometimes this means adding a pure culture—for example, a particular strain of yeast or spores from a specific mold. For some fermentations you can also add a little bit of a finished fermentation to a new one to inoculate it, such as adding old vinegar to a new batch of vinegar. This old-to-new inoculation is also called backslopping.

inoculum
The stuff you use to inoculate a fermentation. For example, a pure strain of yeast, pure koji spores, or old vinegar.

koji
Making koji lets us make miso, garum, and other complex, rich-tasting things from relatively simple starting ingredients. Koji is what you get when you grow the mold *Aspergillus oryzae* on steamed, cooled grains in a humid warm place for two days— the koji is the mold + the grains, which get bound together into a kind of slab or cake by the mold mycelium. Koji is rich in enzymes produced by the mold, especially amylase (which breaks starches down into sugars) and protease (which breaks protein down into free amino acids). These enzymes make the grains of the koji sweet and umami-tasting, and when you mix koji with another ingredient (like soybeans, which is how you make miso in Japan, or yellow peas, which is how we make miso here), they will also break down that ingredient's starches and proteins, creating fermentable sugars for yeasts and lactic acid bacteria to ferment, and umami flavors.

lactic acid
The sour acid in yogurt, sauerkraut, and other lacto-fermented products. It is an organic acid produced by lactic acid bacteria (LAB) from sugar, often in slightly salty environments. Producing lactic acid slows down the growth of other less acid-tolerant microbes which might cause spoilage, giving the lactic acid bacteria less competition and making fermented food safer for us to eat.

lactic acid bacteria
The bacteria we use for making sauerkraut, cultured dairy, lacto plums, etc. It's a group of bacteria that consume sugar and produce lactic acid as a waste product of their metabolism. Many species of Lactic Acid Bacteria (also abbreviated as LAB) are present on our skin and on the outside of plants, and will often begin fermenting plants, dairy, etc. without inoculation by a pure strain. The process

of intentionally using LAB to ferment sugars into acid is called lactofermentation, and is enhanced by adding small amounts of salt (2-8%) which LAB can tolerate but other microorganisms cannot, and removing oxygen, which stops spoilage by mold.

lacto-fermentation
Fermenting the sugars in an ingredient into lactic acid, using lactic acid bacteria.

metabolism/metabolize
The chemical transformations that an organism uses to live. Often this means that a cell getting energy from metabolizing one organic molecule into a different organic molecule. For example, yeast like *Saccharomyces cerevisiae* primarily get their energy from metabolizing sugar into ethyl alcohol, and lactic acid bacteria by metabolizing sugar into lactic acid. We take advantage of the metabolic processes of microbes to do lactofermentation and to make beer, vinegar, and koji.

microbe
Another name for a microorganism.

microorganism
A living organism that is microscopically small. We use microorganisms such as bacteria, yeasts, and molds for fermentation. Pretty much any surface that hasn't been very recently sterilized is covered in microorganisms, which are also found on our skin, in our intestines, in the soil, and pretty much everywhere else on earth. Yeasts and molds are both types of fungi which, like animal cells, have a separate nucleous holding DNA and various other separate structures called organelles that carry out the cell's reproductive and metabolic processes. Bacteria (like acetic bacteria and lactic bacteria) are an older, smaller, and simpler life-form with little internal structure, no organelles, and DNA floating around without a nucleus.

miso
A salty, umami-rich, sometimes sweet, sometimes tangy, sometimes very funky-smelling fermented paste from Japan made in two fermentation stages. In the first stage, steamed rice, barley, or soybeans are cooled and dusted with spores of *Aspergillus oryzae* mold, which is allowed to grow for about two days to make koji. The koji is mixed with boiled soybeans and salt and then left to ferment and age for 2 weeks to 2 years. Miso can also be thought of a process, and a template for transforming ingredients through fermentation. We borrow the technique of making miso and use Nordic ingredients—pearl barley in place of rice for the koji, and protein-rich yellow peas instead of soybeans to make Pea-so.

mold
A mold is a type of fungus. Molds form microscopic filaments called hyphae, with the mold cells themselves existing inside the hyphae. The interconnected network of hyphae that forms is called mycelium. The network of the mycelium will usually penetrate the material that the mold is using for food, and the mold cells produce enzymes that it secretes through the tips of the hyphae to break down and extract energy from the materials in its food source. The mold that we use the most is *Aspergillus oryzae*, for making koji. In koji, the mycelium looks like a fluffy white mat that holds the grains of rice or barley together. The mycelium eventually produces spores on the end of the hyphae, which makes it look extra-fluffy and sometimes green, and these spores can be used to inoculate or 'seed' another batch of koji.

pH
A measurement of acidity or alkalinity. The lower the pH, the more acidic something is— so pH is useful to know if you're relying on acidity as a preservative, for example in vinegar, lactofermentations, or kombucha. Acids have a pH lower than 7, pure water has a pH of 7, and alkaline substances have a pH above 7. Wine has a pH around 4, stomach acid about 1. A pH of 4 is 10 times as acidic as a pH of 5, and a pH of 3 is 10 times more acidic than a pH of 4. Technically pH is the negative log base 10 of hydronium ion concentration so pH 3 would have 0.001 moles of acid per liter.

protease/proteolytic enzyme
An enzyme that breaks down proteins into their amino acid building blocks. One of these, glutamic acid, is responsible for umami flavor. Aspergillus oryzae produces proteases that make miso, shoyu, and our garums rich in umami flavor.

protein
A molecule made from a long chain of chemically linked amino acids. Muscle fibers and enzymes are both made of different specialized proteins. Protein chains are folded into shapes that help them do their jobs and unfolding these shapes is what gives cooked eggs, meats, and cheese their harder texture. Individual amino acids, especially glutamic acid or glutamate, have a flavor called "umami" that we intentionally break down proteins with enzymes in miso and garum to develop.

proteolysis
The process of breaking down proteins (which are made from long chains or strings of linked amino acids) into individual free amino acids. This happens in miso and garum, because of the proteolytic enzymes produced by *Aspegillus oryzae* in koji.

spore
Like a seed for a fungus. We use *Aspergillus oryzae* to inoculate barley to make koji. The spore is a specialized cell that the fungus produces to spread itself to new locations once it starts running out of food in its current home. Spores are also called conidia, and are produced on stalks called conidiophores at the tips of the fibers called hyphae that molds build to live in. This makes it easy for the spores to be dispersed through the air.

starch
Found in grains, potatoes, etc. A molecule made of many glucose molecules linked together chemically in a long string or chain. Starch can be converted into sugar molecules by breaking these chains down, which is what *Aspergillus oryzae* does that makes it useful for fermentation. Starch is made from two different types of sugar chains, amylose (which is one long chain like a string) and amylopectin, which has many branched chains connected together (it looks like a tree branch or root). Amylose gets broken down more slowly by amylases than amylopectin does, and starches tend to be more sticky or waxy the more amylopectin they contain.

substrate
Substrate has different meanings depending on the context. For microbial growth and fermentation, it refers to the material that the microbes grow in and ferment. In the context of enzymes, the substrate is the molecule that is being modified or broken down by the enzyme (into a product or products.)

sugar
A sweet-tasting, soluble carbohydrate (also called a saccharide) that can bind to other sugar molecules in chains to make larger molecules. Glucose and fructose are important monosaccharides, and sucrose or table sugar is a disaccharide made from a glucose and a fructose bound together. Many microbes (lactic acid bacteria, yeasts) feed on sugars directly. Some other microbes (like *Aspergillus oryzae* mold) produce enzymes to break down polysaccharides into smaller sugar molecules.

vinegar
Vinegar is what you get when you ferment an alcoholic liquid (like wine, beer, cider, etc.) with acetic acid bacteria and give them lots of oxygen.

yeast
Yeast in a culinary sense usually means the species *Saccharomyces cerevesiae*, which is the microbe responsible for creating alcohol in beer and wine and making bread rise. Yeasts are a type of fungus, although unlike mold, they stay in single-cell form and don't make interconnected networks. Other yeasts you might encounter in fermented foods are *Brettanomyces* and *Torula* species, sometimes more broadly called "wild" yeasts.

Notes