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What Is Actually in the Jar?

Marmite, Vegemite and their relatives, as read by a 300 MHz magnet

The plain-language edition of technical white paper PNA-WP-2026-YE01, for readers who like their science the way they like their Marmite: spread thin.

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The 30-second version

Yeast-extract spreads are what you get when a brewery's leftover yeast is persuaded to digest itself and the result is boiled down to a dark, salty paste. We put five of them (Marmite and Marmite XO from Britain, Vegemite and Promite from Australia, and New Zealand's own Marmite) into a 300 MHz NMR spectrometer, an instrument that takes a roll call of the molecules in a sample without having to separate them. Each jar answered with a pattern of its own. The four yeast extracts share the same savory core and differ, of all things, in their sugars; the fifth is mostly vegetable protein and table sugar. The same quick test could anchor a factory's quality control, and with a tasting panel beside it could explain why each jar tastes the way it does. One jar of each was measured, so this is a snapshot and not a census.

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Love it. Hate it. Measure it.

Few foods divide a breakfast table like yeast extract. To its admirers it is the taste of home: dark, salty, deeply savory, faintly beefy without ever having met a cow, and at its best spread on hot buttered toast in a layer thin enough to read through (sausages optional). To everyone else it is a practical joke that Britain, Australia and New Zealand have been playing on their visitors for more than a century. (Full disclosure: the author is firmly in the first camp.)

This paper does not try to settle that argument. It asks a chemist's question instead: what is actually in the jar? Not the ingredients list, which for Marmite is five items long and begins, unhelpfully, with "yeast extract", but the molecules themselves.

To find out, we took five jars. Marmite and its long-matured sibling Marmite XO came from Britain, and Vegemite and Promite from Australia. From New Zealand came the local Marmite, which shares a name with the British one and not a great deal else. A dab of each was dissolved in a little water and lowered into a nuclear magnetic resonance (NMR) spectrometer, an instrument built around a magnet strong enough to wipe any credit card that wanders too close. It reports which molecules a sample contains without anyone having to separate them first.[1]

The full account of what came out runs to 105 pages, 31 figures and 94 references, and can be warmly recommended to anyone who enjoys the phrase "multiplicity-edited gHSQC". This is the edition for everybody else. It keeps the story, the best pictures and a handful of numbers, and it carries one warning from the start: we measured a single jar of each product, so what follows is a well-lit snapshot and not a census.

So what is yeast extract, exactly?

Beer's leftovers, persuaded to digest themselves

Beer is made by yeast, and yeast, being alive, multiplies as it works. A brewery ends every batch with far more yeast than it began with, and after spent grain that surplus is the largest leftover the industry produces.[2] The idea of turning it into food is usually credited to the German chemist Justus von Liebig, of meat-extract fame, who observed in the nineteenth century that yeast could be concentrated, bottled and eaten in much the same way.[3,4]

The trick is to let the yeast do the hard part. Warm the cells in salty water to 45 to 55 °C, about the temperature of a bath you would get out of quickly, and they die. Their internal compartments leak, and the digestive enzymes that had been safely locked away set about dismantling the cell from the inside. Proteins fall apart into short fragments called peptides and then into free amino acids, among them glutamate, the molecule behind the savory taste known as umami. The cell's RNA is clipped into small pieces. Its stored sugars are nibbled away. The trade calls this self-digestion *autolysis* and lets it run for anything from half a day to two days.[5,6]

The tough, empty cell walls are then spun out in a centrifuge, and the clear brown liquid that remains is boiled down until roughly three-quarters of it is solids. The heat does more than drive off water. Amino acids and sugars react with one another in the same browning chemistry that makes toast taste of toast, and

that is where the dark color and the roasted, meaty smell come from. Stir in more salt, a little vegetable and spice extract and some B vitamins, fill the jars while the paste is hot, and the job is done.

One point of etiquette. Yeast extract counts as an *ingredient* and not as an additive: in Europe it carries no E number and is simply listed by name.[7] Its savoriness comes from glutamate released from the yeast's own protein and not, so far as any of these five labels say, from added MSG.

A very short history, with puns

Marmite has been made this way since 1902 in Burton upon Trent, a town chosen because its breweries, Bass above all, had yeast to spare.[3] (The name is French for a lidded cooking pot, which is why there is one on the label.) It found a second career as a health food once vitamins had been discovered, and a moment of real glory in 1931, when the physician Lucy Wills reported that yeast extract cured a dangerous anemia of pregnancy among mill workers in Bombay. The ingredient responsible turned out to be the vitamin now called folate.[8]

Australia made its own after the First World War, when Marmite became hard to get. A Melbourne chemist, Cyril Callister, worked out a version from the yeast of the Carlton and United brewery, and it went on sale in 1923 as Vegemite. It sold so badly against the entrenched British product that for seven years it was renamed "Parwill", so that the advertisements could say "Marmite, but Parwill" (say it aloud: Ma might, but Pa will). It recovered, and by the late 1940s it was reported to be in nine of every ten Australian homes.[9,10]

New Zealand took a third road. The Sanitarium Health Food Company began by importing British Marmite and, during the 1930s and 1940s, worked out a recipe of its own in Christchurch, with sugar and caramel in it and a milder taste.[11,12] When earthquake damage closed the factory in 2012 and the shelves stood empty for the better part of a year, the country called it "Marmageddon" and was only partly joking.[11,13]

And vegetable extract?

The fifth jar, Promite, is the odd one out, and it was chosen for exactly that reason. It appeared in Australia in the 1950s as a sweeter, milder rival to Vegemite, and its label today calls it a "vegetable extract spread". The first ingredient is vegetable protein extract (39 percent), the second is sugar, and yeast extract comes third.[14,15]

Vegetable protein extract is the other way to make a savory brown paste. Instead of letting yeast digest itself, you take a protein-rich plant material such as soy, corn or wheat gluten and break its protein down into amino acids, classically by cooking it in hydrochloric acid and then neutralizing the acid, which conveniently leaves salt behind. The industry calls the result hydrolyzed vegetable protein, or HVP. It is rich in glutamate, it is dark, it is cheap, and it is the nearest thing to yeast extract that is not yeast extract, which is exactly why a test that can tell the two apart is worth having.

Like every trade, this one has a vocabulary of its own. Table 1 is a phrase book.

Table 1. How to sound as though you work there: a phrase book of the yeast-extract trade.[1,5]

The term	What it means in plain English
Spent yeast	The surplus yeast a brewery has left when the beer is made. It arrives as a beery slurry and is the raw material of the classic spreads.

The term	What it means in plain English
Primary-grown yeast	Yeast grown on purpose, usually on molasses, to be made into extract, as opposed to yeast collected from a brewery.
Debittering	Washing the yeast to remove the bitter hop resins that cling to it from the beer.
Autolysis	Self-digestion. The dead cell's own enzymes take it apart from the inside: warm, salty, and half a day to two days long.
Plasmolysis	Opening the cells up with salt or a little solvent so that their contents leak out and digestion can begin.
Hydrolysis, hydrolysate	Breaking large molecules into small ones with water, helped along by enzymes or by acid. The hydrolysate is what you end up with.
Autolysate or extract?	An autolysate still contains the cell walls. An extract has had them removed. The spreads are extracts.
HVP	Hydrolyzed vegetable protein: plant protein broken down into amino acids, traditionally with acid. The savory base of a "vegetable extract".
Free amino nitrogen	How much of the nitrogen sits in free amino acids instead of in protein and peptides (also quoted as the AN/TN ratio). A measure of how far digestion has gone.
Umami	The savory taste of glutamate: the fifth basic taste, beside sweet, sour, salty and bitter.
I+G	Trade shorthand for inosinate and guanylate, two flavor enhancers of the 5′-nucleotide family, made from RNA, that multiply the umami of glutamate.
Kokumi	"Mouthfulness": a sense of richness and lasting flavor contributed by certain small peptides that have little taste of their own.
Maillard reaction	The browning chemistry of amino acids and sugars under heat. It makes toast taste of toast and yeast extract dark and roasted.
Solids, or dry matter	Everything that is not water. A spread is boiled down to roughly 70 to 80 percent solids.

How a magnet reads a jar

NMR is the laboratory cousin of the hospital MRI scanner. An MRI scanner makes a picture of where the water is in your knee. An NMR spectrometer makes a list of which molecules are in your sample.

Here is the whole idea in one paragraph. Nearly every molecule in food is studded with hydrogen atoms, and the nucleus of a hydrogen atom behaves like a tiny compass needle. Put the sample in a strong magnet, give it a short burst of radio waves, and the hydrogens ring back like struck bells. The pitch of each bell depends on exactly where that hydrogen sits within its molecule, so a hydrogen on the amino acid alanine does not ring at the same pitch as one on a sugar. Plot all the pitches along a line and you have a spectrum, in which each kind of molecule contributes a small set of peaks of its own, always at the same positions. Chemists call the position of a peak its chemical shift and measure it in parts per million, which is why the axis of every figure here is marked in ppm.

Nothing has to be separated, purified or reacted beforehand. A dab of the spread is dissolved in heavy water, which is ordinary water with its hydrogens swapped for a heavier form that the instrument ignores, so that the water does not drown out everything else. The tube goes into the magnet, and a few minutes later every

hydrogen-bearing molecule that is present in a reasonable amount has reported in at once. (Table salt contains no hydrogen, so it stays silent, a point we shall come back to.) Figure 1 shows what the five jars said.

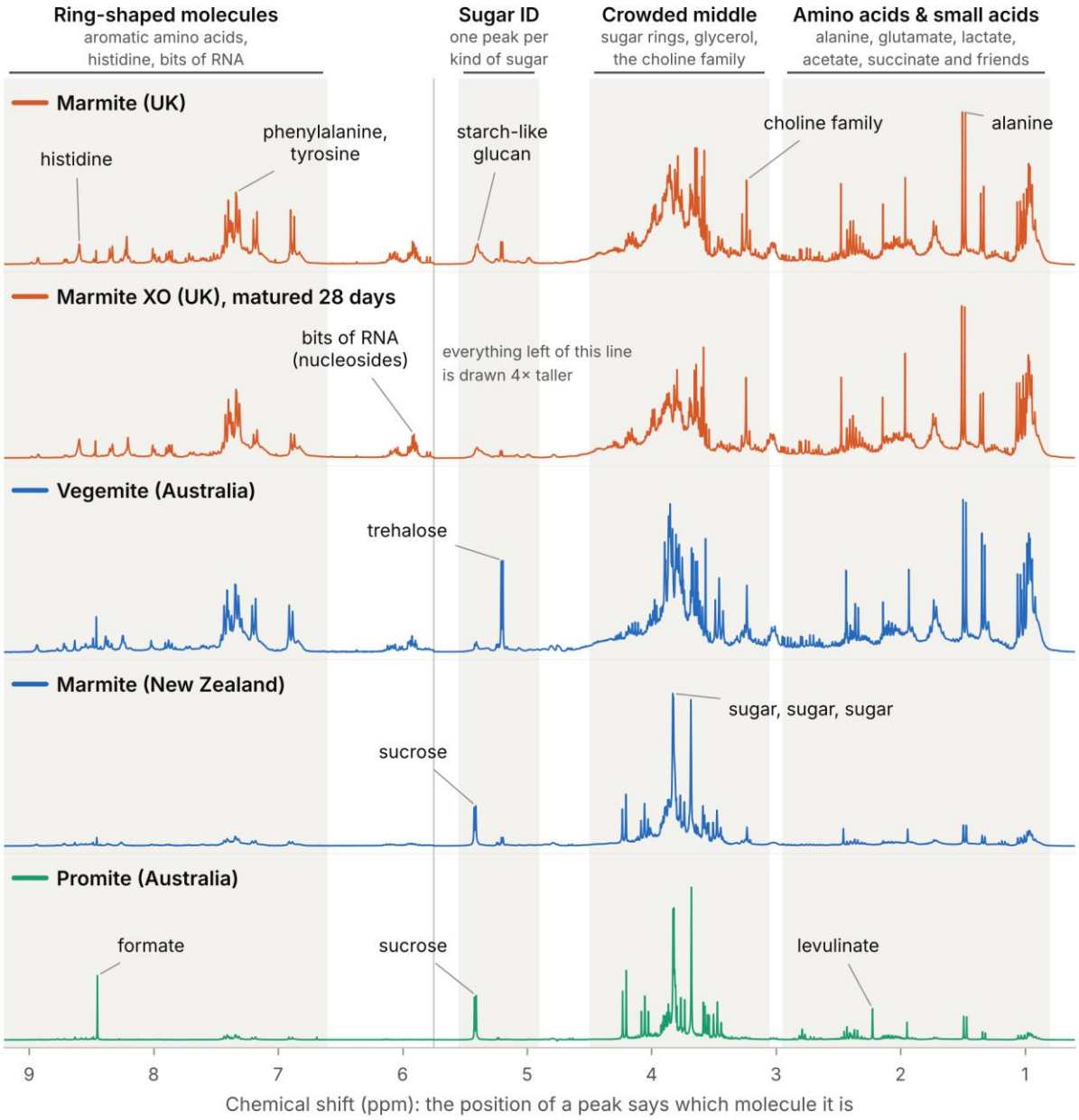


Figure 1. Five jars, five barcodes. The ^{1}H NMR spectra of the five spreads (300 MHz, in heavy water). Each trace is scaled to its own tallest peak, and everything to the left of the vertical line is drawn four times taller so that the small signals can be seen. The shaded bands mark the four neighborhoods of the spectrum, and a few landmark peaks are named. Orange, the British jars; blue, the Australasian yeast extracts; green, the vegetable-extract spread.

Reading the barcode

Read from right to left, each of these spectra has four neighborhoods. On the far right live the amino acids and the small organic acids, which are the products of digested protein and of the yeast's own metabolism.

The tall twin peak at about 1.5 ppm is alanine, the most conspicuous free amino acid in these extracts, which we shall shortly press into service as a ruler. The crowded middle is where the sugars, glycerol and the choline family pile on top of one another. Between about 5 and 5.5 ppm lies a quiet stretch in which each kind of sugar shows a clean signal of its own, which makes it the most useful inch of the entire spectrum. And at the far left are the ring-shaped molecules: certain amino acids, and the remains of the yeast's RNA.

Even before any chemistry is done, the eye can sort these jars. The two British traces could be twins. Vegemite has much the same right-hand side but a sharp extra spike in the sugar stretch. The New Zealand Marmite and Promite are both dominated by a few enormous sugar peaks in the middle. And the left-hand side of Promite is all but empty, apart from one needle-sharp peak that the others have only in miniature.

Counting molecules: the only real equations in this paper

NMR has one property that endears it to chemists: it does not play favorites. The area under a peak is proportional to the number of hydrogen nuclei that produce it, whatever molecule they happen to belong to.[16] In symbols, where ∝ means "is proportional to":

$$\textbf{area of a peak} \;\propto\; \textbf{number of molecules} \times \textbf{hydrogens per molecule behind that peak} \tag{1}$$

So to compare two substances in the same jar, take the two peak areas, divide each by its number of hydrogens, and divide one result by the other:

$$\textbf{molecules of X per molecule of Y} = \textbf{(area of X} \div \textbf{hydrogens of X)} \div \textbf{(area of Y} \div \textbf{hydrogens of Y)} \tag{2}$$

Here is a worked example from the Vegemite spectrum. The sugar trehalose gives a peak near 5.2 ppm that comes from 2 hydrogens in each molecule. Alanine gives its peak near 1.5 ppm from 3 hydrogens in each molecule. The trehalose peak has 0.83 times the area of the alanine peak. Therefore:

$$(0.83 \div 2) \div (1 \div 3) \approx 1.25 \text{ molecules of trehalose per molecule of alanine}$$

In that jar of Vegemite there are about five molecules of trehalose for every four of alanine. No calibration curve was needed, and no bottle of pure trehalose: two areas and some counting on fingers.

Every number in this paper is a ratio of this kind, and most are measured against the alanine in the same jar. That makes alanine a ruler and not a constant. If one jar happens to hold more free alanine than another, all of its ratios shrink to match, so the ratios compare one jar with another only roughly. To turn them into grams, a weighed amount of a standard compound is added to the tube and its peak becomes the yardstick:

$$\textbf{amount of X} = \textbf{(molecules of X per molecule of standard)} \times \textbf{(amount of standard added)} \tag{3}$$

We have not yet done that for these five jars. It is the first item on the to-do list at the end.

When one line is not enough: the map

The crowded middle of Figure 1 is a problem. Dozens of molecules overlap there, like an orchestra playing every note at once. The remedy is a second kind of experiment that spreads the same signals over two dimensions: from left to right by the pitch of the hydrogen, as before, and from top to bottom by the pitch of the carbon atom to which that hydrogen is attached. Every hydrogen–carbon pair becomes a blob on a map, and molecules that overlapped hopelessly on the line now sit in plots of their own (Figure 2).

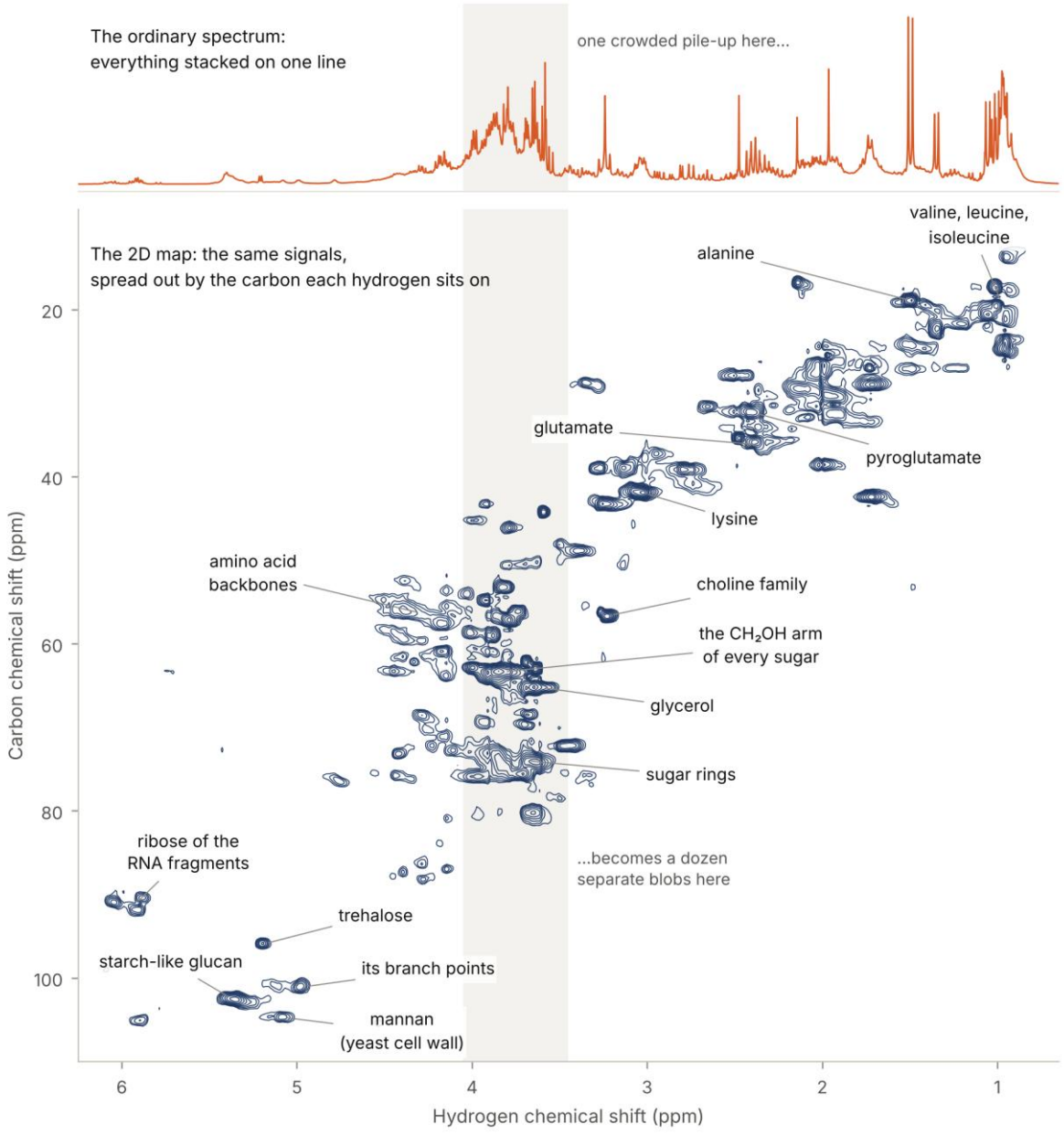


Figure 2. From a line to a map. Top, the ordinary spectrum of Marmite XO, with everything stacked on one line. Below, the two-dimensional map of the same sample (a ^{1}H–^{13}C HSQC spectrum), in which each blob is one kind of hydrogen sitting on one kind of carbon. The shaded strip shows a single crowded pile-up on the line coming apart into a dozen or more separate blobs on the map.

Reading those maps was the main labor of the technical paper. Across the five jars we put names to 155 different hydrogen–carbon signals, to another 83 signals from a companion experiment that links atoms two or three bonds apart, and to about thirty fine-structure patterns from a third. Fifty constituents were then graded, jar by jar, as confirmed, probable or tentative.[1] Roughly a quarter of the blobs on the maps still have no name, which seems only fair. A food with no secrets left would be a dull thing to spread on toast.

Five jars, five personalities

Table 2 gives the short version of what each jar contains. The longer version comes in two parts: what the yeast-based jars have in common, and the one unexpected thing that divides them.

Table 2. Five jars at a glance. The label information is from current retail labels;[15,17–20] *the NMR findings are those of the technical white paper*[1] *and describe one jar of each product.*

The jar	The label says	The magnet says	In a nutshell
Marmite (UK)	Yeast extract, salt, vegetable juice concentrate, B vitamins, natural flavoring. Salt 10.8 g and sugars 1.2 g per 100 g.	The full savory core. Plenty of starch-like glucan and little trehalose. Betaine. As much pyroglutamate as glutamate.	The benchmark: salty and savory, with nothing to sweeten it.
Marmite XO (UK)	The Marmite recipe, matured for 28 days instead of 7.	Marmite's near-twin, with about a quarter of the trehalose and half of the glucan (counted against alanine), and the clearest RNA-fragment signals of the five.	Marmite, further down the same road.
Vegemite (Australia)	Yeast extract, salt, potassium chloride, malt extract, color, flavors, B vitamins. No sugar listed.	The same core, but trehalose is the star and the glucan has almost gone. No betaine. Signals of oily fatty-acid chains, seen in no other jar.	The yeast's own sugar survived.
Marmite (New Zealand)	Yeast, sugar, salt, potassium chloride, caramel color, corn maltodextrin, iron, B vitamins, herbs and spices.	Table sugar towers over everything. Underneath, an extract of the Vegemite kind with its trehalose intact. About one-eighth of the sugar has split into glucose and fructose. Some ethanol.	A Vegemite-style base, sweetened.
Promite (Australia)	Vegetable protein extract (39 percent), sugar, yeast extract, water, caramel color, cornflour, salt, glucose syrup and more. Sugars 18.1 g per 100 g.	Table sugar and glucose; the amino acids of digested plant protein; levulinate and formate, the calling cards of acid hydrolysis; citrate. None of the yeast markers.	A different animal. Or rather, vegetable.

What the four yeast jars share

Start with the common ground, because it is most of the story. Each of the four yeast-based jars contains sixteen to eighteen free amino acids, the confetti of digested protein, with alanine the most conspicuous and glutamate, the umami one, prominent among them. Each contains small peptides, which are bits of protein not yet fully taken apart. Each contains the choline family, which is what remains when the yeast's cell membranes are dismantled, together with glycerol, a few small acids (succinate, lactate and acetate), fragments of RNA and three kinds of carbohydrate. Every one of them, in short, is recognizably a yeast that has digested itself, and the digestion is written all over the spectrum.

The sugar story

The surprise is where they differ. It is not in the amino acids, the salt or the vitamins. It is in the sugars, and only one of the sugars involved ever saw the inside of a sugar bowl.

A yeast cell keeps two energy reserves. Glycogen is its starch: long, branching chains of glucose units, laid down when times are good. Trehalose is its emergency ration: just two glucose units joined together, stockpiled when the cell is under stress, and a protection against heat and drying as well as a food store.[21] Brewery yeast brings along a third relative, the dextrins left over from the beer, which are branched chains of glucose too. We shall call the whole family of chains "starch-like glucan". In the spectrum the chains appear as a broad hump near 5.4 ppm, broad because they come in every length, and trehalose appears as a crisp pair of lines near 5.2 ppm. Figure 3 zooms in on that stretch.

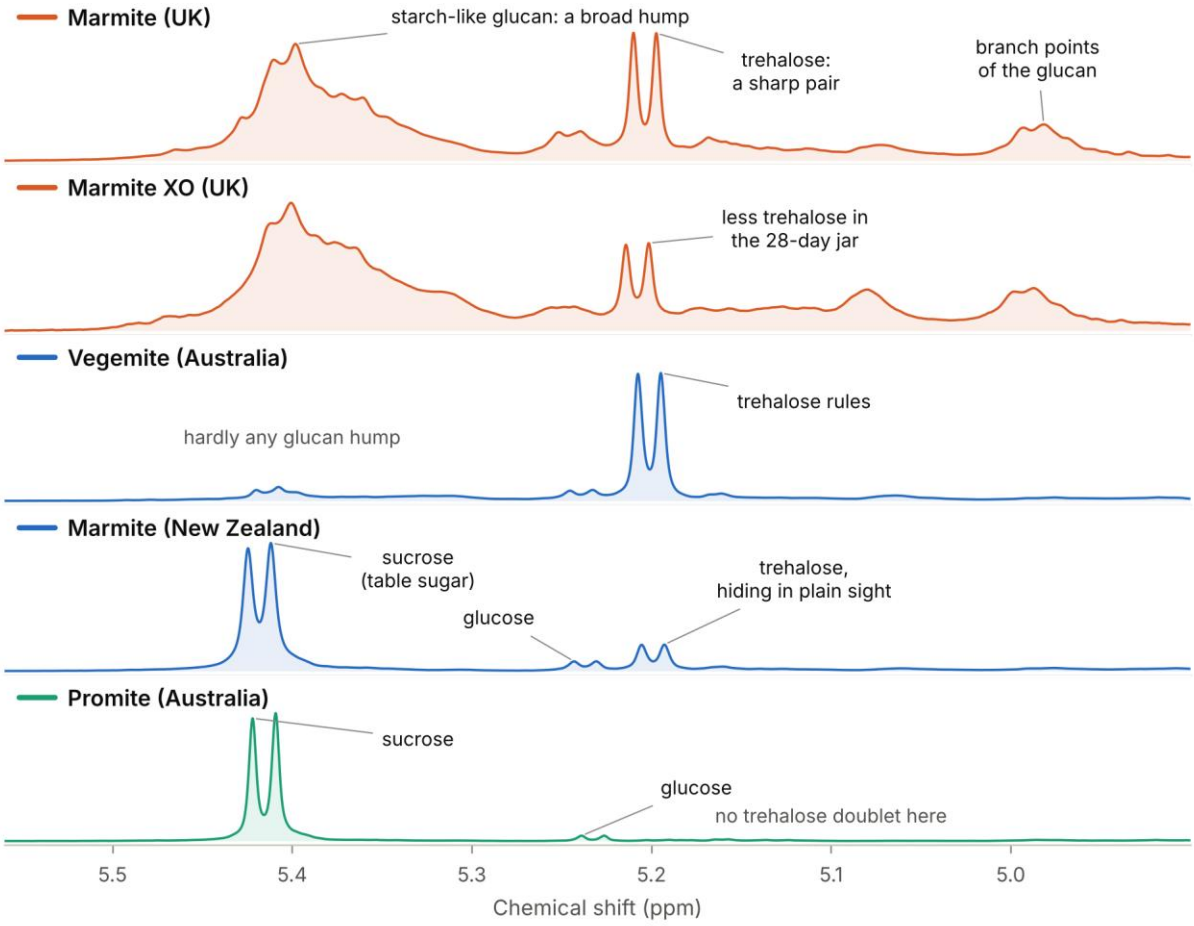


Figure 3. The most useful inch of the spectrum. The sugar stretch of each jar, each scaled to its own tallest peak. A broad hump means chains of glucose (starch-like glucan). A sharp pair of lines means a small sugar: trehalose near 5.2 ppm, table sugar (sucrose) near 5.4 ppm, and free glucose just to the left of trehalose.

The pictures tell it at a glance, and Equation 2 puts numbers on it (Figure 4). British Marmite holds roughly one molecule of trehalose for every three or four of alanine, and about nine glucose units of glucan for each trehalose. In Marmite XO, which is matured for 28 days where the standard product gets seven,[18] the trehalose is down to about a quarter of that. In Vegemite there are five molecules of trehalose for every four of alanine, some four times the Marmite figure, and the glucan hump has all but vanished: less than one

glucose unit of glucan per trehalose, against nine and fifteen in the two British jars. That last comparison is the sturdy one, because it sets two sugars in the same jar against each other and does not lean on the alanine ruler at all. The same kind of raw material, the same basic process, and opposite sugar ledgers.

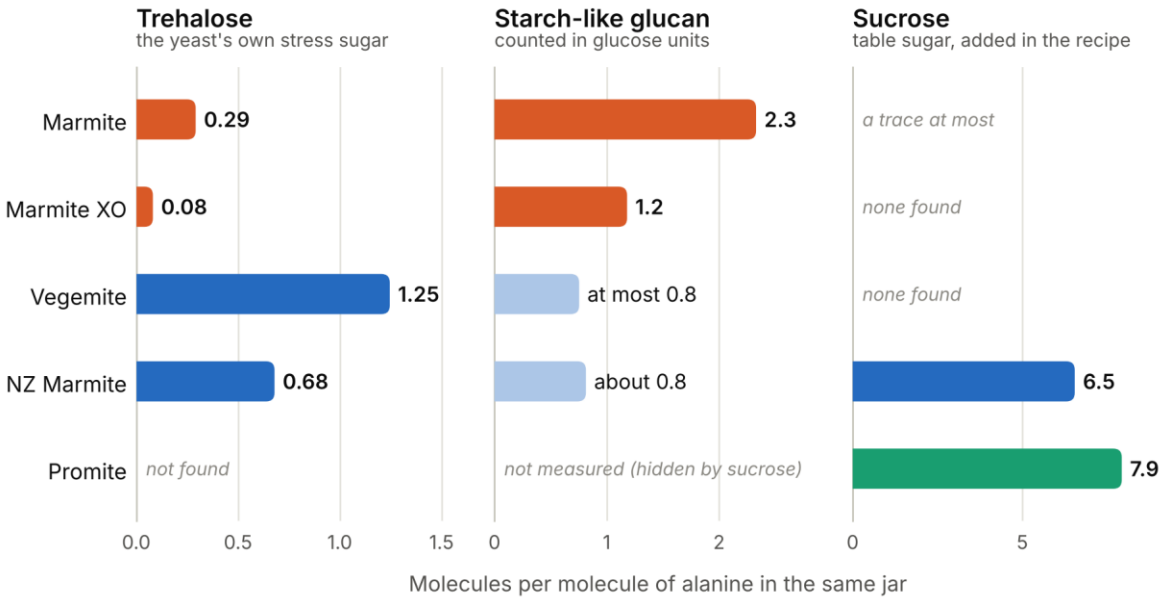


Figure 4. The sugar ledger. Trehalose, starch-like glucan and sucrose in each jar, counted with Equation 2 in molecules (for the glucan, glucose units) per molecule of alanine. Paler bars are rough values or upper limits. One jar of each product; the trehalose and sucrose values are good to about one part in ten, the glucan values to one part in five at best.

Why? There are two explanations on offer, and the data cannot yet choose between them. The first concerns the condition of the yeast on arrival. Yeast that has been stored for a while, or harvested after a long cold rest, converts its glycogen into trehalose, so it turns up rich in trehalose and poor in glycogen, and fresh yeast is the other way around.[21,22] The second concerns what happens in the tank. Yeast carries enzymes that eat trehalose all through a long, mild, salty digestion, and a sharp burst of heat at the start switches them off.[23] The British process looks like the long, mild kind, and the drop from Marmite to Marmite XO is at least consistent with trehalose being eaten as the weeks go by. With one jar of each, though, we cannot rule out that the two batches simply began with different yeast.

The New Zealand Marmite supplies the twist. Its spectrum is so dominated by added table sugar, six or seven molecules of sucrose for every alanine, that on a first reading its trehalose was taken for a trace. The numbers say otherwise: about two molecules of trehalose for every three of alanine, more than twice the British figure, with only about a third of Marmite's glucan. Under its blanket of sugar the New Zealand jar is an extract of the Vegemite kind and not of the British kind. There is one trehalose molecule in it for every ten of sucrose, hiding in plain sight. About one-eighth of that sucrose, moreover, has split into its two halves, glucose and fructose. That suggests that the sugar goes in late or that the cooking is gentle, and it could serve as a built-in thermometer for the process.

Promite goes further still, with about eight molecules of sucrose per alanine, and shows no trehalose at all.

Promite: a different animal (or rather, vegetable)

Promite differs in kind and not merely in degree. Where the yeast jars show RNA fragments, the choline family, trehalose and succinate, Promite shows none that we could detect. What it shows instead is a short list of things the yeast jars lack or have only in traces. There is levulinate, a small molecule formed when sugars and starches are cooked in strong acid, and long used as the chemical giveaway that separates acid-made soy sauce from the brewed kind.[24] There is formate, another product of sugars roughed up by acid and heat, which is the tall sharp peak at the far left of Promite's trace in Figure 1. And there is citrate, which the label declares as an acidity regulator.

That is the profile of acid-hydrolyzed vegetable protein with sugar, which is just what the first two ingredients on the label would lead anyone to expect. The label also lists yeast extract, in third place. We have no reason to doubt it. We can say only that whatever is there lies below what these spectra can see. (Levulinate, we should add, is graded "probable" and not "confirmed" in the technical paper, pending the simple test of stirring in a little of the real thing and watching the peak grow.)

Plot twists

An earlier version of the technical paper was written from pictures of the spectra. For the current one we went back to the numbers underneath, and the numbers had opinions.

The RNA peak that wasn't

Flavor chemists care a great deal about one family of RNA fragments, the 5′-nucleotides (the "I+G" of Table 1), because they multiply the umami of glutamate several times over, an effect that has been textbook material since 1967.[25] A sharp peak at 8.6 ppm in the British jars had been read as belonging to that family, and a pleasing story followed from it: longer maturation, more nucleotides, more umami. The two-dimensional maps disagreed. The 8.6 ppm peak belongs to histidine, an amino acid. The RNA debris that really is present turns out to be mostly nucleosides, which are nucleotides that have lost their phosphate group and with it their flavor-enhancing power. The umami-synergy story has therefore been withdrawn until somebody shows that the nucleotides are there. The right experiment exists (it listens to phosphorus atoms instead of hydrogen) and is on the list.

The glutamate that got away

Digested yeast protein releases a good deal of glutamine, a close relative of glutamate. Given warmth and time, glutamine can go one of two ways. An enzyme can turn it into glutamate, which is umami and therefore a good thing. Or it can curl up on itself and become pyroglutamate, which is not. In the two British jars there is about as much pyroglutamate as glutamate; in Vegemite and the New Zealand jar there is about half as much. This is just the sort of number a process engineer likes to see on a chart, since each pyroglutamate is, more or less, a glutamate that got away.

One peak, three molecules

A single line near 3.2 ppm had been filed under "choline". Look closely and it is three lines (Figure 5). The big one is glycerophosphocholine, GPC for short, a fragment of the yeast's cell membranes. The small one to its right is free choline, at roughly a third of the GPC in every yeast jar. The one to its left is betaine, and it appears only in the two British jars. We do not know why. Betaine comes with sugar-beet molasses, with

cereals and with some vegetable concentrates, so it may be a clue to what the yeast was fed or to one of the other ingredients. For now it is a British marker in search of an explanation.

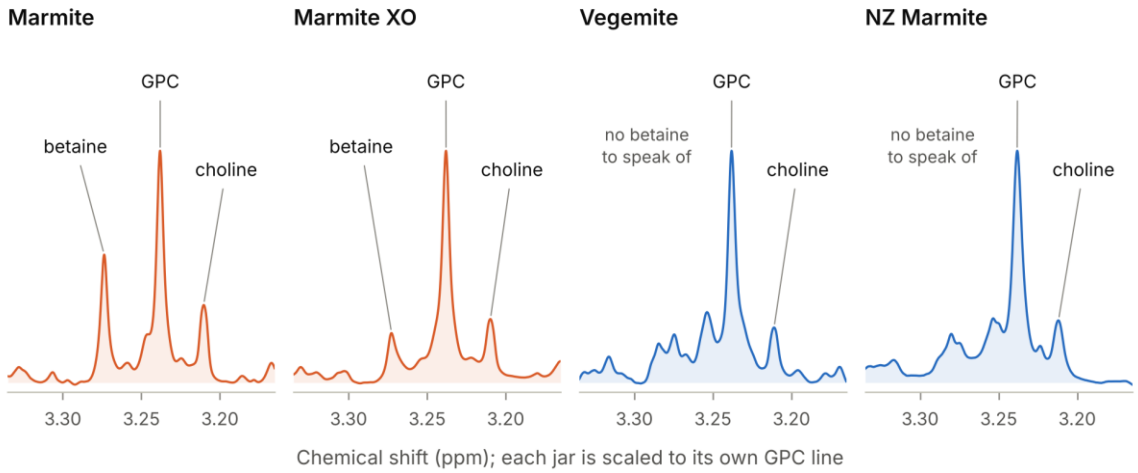


Figure 5. One peak, three molecules. A close-up of the "choline" signal in the four yeast extracts, each scaled to its own GPC line. GPC (glycerophosphocholine) and free choline appear in all four. Betaine stands beside them only in the two British jars.

Maps are for naming, not for weighing

One last note for the technically inclined. The handsome two-dimensional maps are for identifying molecules, not for measuring how much of each is present. When the sizes of the blobs were checked against the plain counting of Equation 2, the two disagreed by as much as a factor of three. The numbers in this paper therefore come from the ordinary one-line spectra, with one exception: the pyroglutamate comparison uses the maps, but only to compare two signals of the same kind, which is the one job they can be trusted with. Table 3 collects the numbers in one place.

Table 3. The scoreboard. Each value counts molecules (for the glucan, glucose units) against other molecules in the same jar. All are from the one-line ^{1}H spectra except the last row, which compares two signals of the same kind on the maps. One jar per product; the trehalose and sucrose values are good to about one part in ten and the rest to one part in five or worse.[1] A dash means that the comparison does not apply.

How many …	Marmite	Marmite XO	Vegemite	NZ Marmite	Promite
Trehalose per alanine	0.29	0.08	1.25	0.68	none found
Glucan units per alanine	2.3	1.2	at most 0.8	about 0.8	not measured
Glucan units per trehalose	9	15	under 1	about 1	–
Sucrose per alanine	a trace at most	none found	none found	6.5	7.9
Free choline per GPC	0.43	0.29	0.30	0.25	–
Betaine per GPC	0.64	0.26	none found	none found	–
Pyroglutamate per glutamate	1.0	1.1	0.6	0.5	–

Why it tastes like that

Now for the part most readers came for. Can the chemistry explain the taste? Up to a point, and with one large caveat: nobody tasted anything in this study. What follows joins our measurements to what is already known about how tastes interact. It is a set of educated guesses, which a tasting panel could confirm or demolish.

All of these spreads start with the same problem. Digested yeast is intensely savory, but it is also bitter, because some of the protein fragments in it are bitter, and by the time it is a spread it is very salty. Each recipe is a different answer to the question of how to make that pleasant.

The British answer is to lean in. Marmite contains next to no sugar (1.2 g in every 100 g) and a great deal of salt (10.8 g).[17] Salt does more than taste salty: it suppresses bitterness, which lets the savory notes through.[26] The result is intensity, held in balance by salt alone.

The Australasian answer is to round the edges with sweetness, which is the most effective tamer of bitterness there is and takes some of the sting out of salt as well.[27] New Zealand Marmite and Promite do it openly, with sugar second on their ingredient lists.[15,20] Vegemite, if our reading is right, does it by an accident of its process. No sugar appears on its label, only a little malt extract,[19] but the yeast's own trehalose has survived in quantity, and trehalose is about 45 percent as sweet as table sugar.[28] Both of the Australasian yeast extracts also replace part of their ordinary salt with potassium chloride, which saves sodium at the price of a bitter, metallic edge,[29] and sweetness helps to hide that too. One family, you might say, turns the volume up and the other adjusts the tone, and the sugar ledger of Figure 4 is the written record of the difference.

The 28-day jar deserves a sentence of its own. Marmite XO is sold as the stronger, fuller-flavored version.[18] What the magnet sees is consistent with a longer digestion (less of the yeast's reserve sugar, clearer RNA debris), but it cannot tell us which of those changes, if any, can be tasted. A long maturation would also be expected to deepen the roasted aroma, and aroma molecules are present in amounts far too small for this method to see.

How a tasting panel would settle it

The guesswork can be replaced by evidence, and flavor science has a well-worn recipe for doing so.

First, recruit a trained sensory panel: ten or a dozen people who have been taught to score saltiness, umami, bitterness, sweetness, roasted notes and "mouthfulness" on a consistent scale, and who taste every sample blind. Second, give them not five jars but dozens: many batches of each product, and pilot batches made different on purpose, with shorter and longer digestion and with more and less heat. Third, put every one of those samples through the magnet. Each sample now has two descriptions, a sensory one (a row of panel scores) and a chemical one (a spectrum), and statistics can search for the parts of the spectrum that rise and fall in step with each score. In its simplest form the answer looks like this:

$$\text{bitterness score} \approx \text{baseline} + (\text{weight}_1 \times \text{compound 1}) + (\text{weight}_2 \times \text{compound 2}) + \ldots \quad (4)$$

The compounds that earn the biggest weights are the suspects. They are only suspects, because things that rise and fall together need not be cause and effect: a batch that was digested for longer contains more of

everything that digestion produces, the guilty and the innocent alike. So the fourth step is the decisive one. Take a plain base, add the suspect at the level found in the jar, and ask the panel whether they can taste the difference; or rebuild the whole taste from pure compounds and leave one out. Flavor chemists call this taste-and-confirm approach sensomics, and it is how ten of the peptides responsible for kokumi were tracked down in a commercial yeast extract.[30]

For these spreads the questions are already lined up. Does trehalose at the level found in Vegemite measurably soften bitterness? How much umami is lost when glutamine ends up as pyroglutamate? Do the bitterness scores follow the peptides that are still undigested? And does anything the magnet can see track the difference between a 7-day and a 28-day Marmite? The magnet will not answer everything by itself. It is deaf to salt and to the aroma molecules, so a serious study would pair it with a salt measurement and with gas chromatography for the aromas. But in one measurement per sample it supplies most of the non-volatile chemistry that a model of taste needs.

From brewery tank to breakfast: the quality-control pitch

Suppose you make this stuff for a living. Your raw material is another industry's leftover, and it varies with the brewery, the beer, the season and how long the yeast sat in a tank before the truck came. Your process is a controlled self-destruction followed by a controlled scorch. And your customers have eaten the product every morning since childhood and will notice if Tuesday's jar is different. How do you keep it the same?

The traditional answer is a list of separate tests: water content, salt, total nitrogen (which goes on the label as "protein"), free amino nitrogen, glutamate, acidity, color, vitamins, microbiology and a tasting panel. Each test answers one question, and most answer it with a single lump sum. Total nitrogen, for instance, counts the nitrogen in proteins, amino acids, RNA fragments and choline without distinction. A batch can pass every one of those tests and still differ in ways that matter, because the tests were never meant to describe the product as a whole.

An NMR spectrum does describe the product as a whole, or at least everything in it that dissolves and carries hydrogen. That suggests three ways of using it, in rising order of ambition.

As a fingerprint

Measure a few dozen good batches and you know what normal looks like, peak by peak. A new batch either looks like the others or it does not. For any single peak the rule is the one used on factory control charts everywhere, in which the scatter is what statisticians call the standard deviation:

$$\textbf{raise a flag if} \quad |\,\textbf{today's value} - \textbf{usual average}\,| \;>\; 3 \times \textbf{usual scatter} \tag{5}$$

A spectrum applies the same idea to a few hundred slices at once. The software that does it carries an intimidating name, principal component analysis, but the principle is no deeper than the line above. Better still, a batch that raises the flag also shows where in the spectrum it went astray, which means which molecule, which usually means which step of the process. The one catch is that "normal" has to be learned properly. A library built from a single month of production will cry wolf at the first change of season, so the reference batches have to span the suppliers and the calendar.

None of this is exotic. Fruit-juice laboratories have run this kind of screening commercially for well over a decade.[31] And in a published NMR study of yeast and plant hydrolysates, the differences from batch to batch were carried by a small handful of compounds, exactly the kind of thing a fixed list of tests misses unless it happens to include them.[32]

As a set of gauges on the process

Certain pairs of peaks behave like gauges on particular steps of the process, and because each is a ratio within a single spectrum, none of them needs calibrating (Figure 6). Trehalose against glucan reports the condition of the incoming yeast and how far the digestion has run. Free amino acids against peptides report how thoroughly the protein has been taken apart. Glutamine, glutamate and pyroglutamate report on heat and time. Lactate and acetate report on hygiene, because the bacteria that spoil brewery yeast produce them. Sucrose against its two halves reports how much heat the sugar has seen.

A manufacturer could follow a single batch from start to finish by drawing a sample from the tank every few hours and watching those gauges move, and could then define “done” as the moment the spectrum arrives where good batches end up, instead of going by the clock. (Strictly speaking the fermentation, the part that makes alcohol, happens earlier, at the brewery. The same magnet can follow that as well, with sugars falling and alcohol rising. For the maker of the spread, though, the process to watch is the self-digestion.)

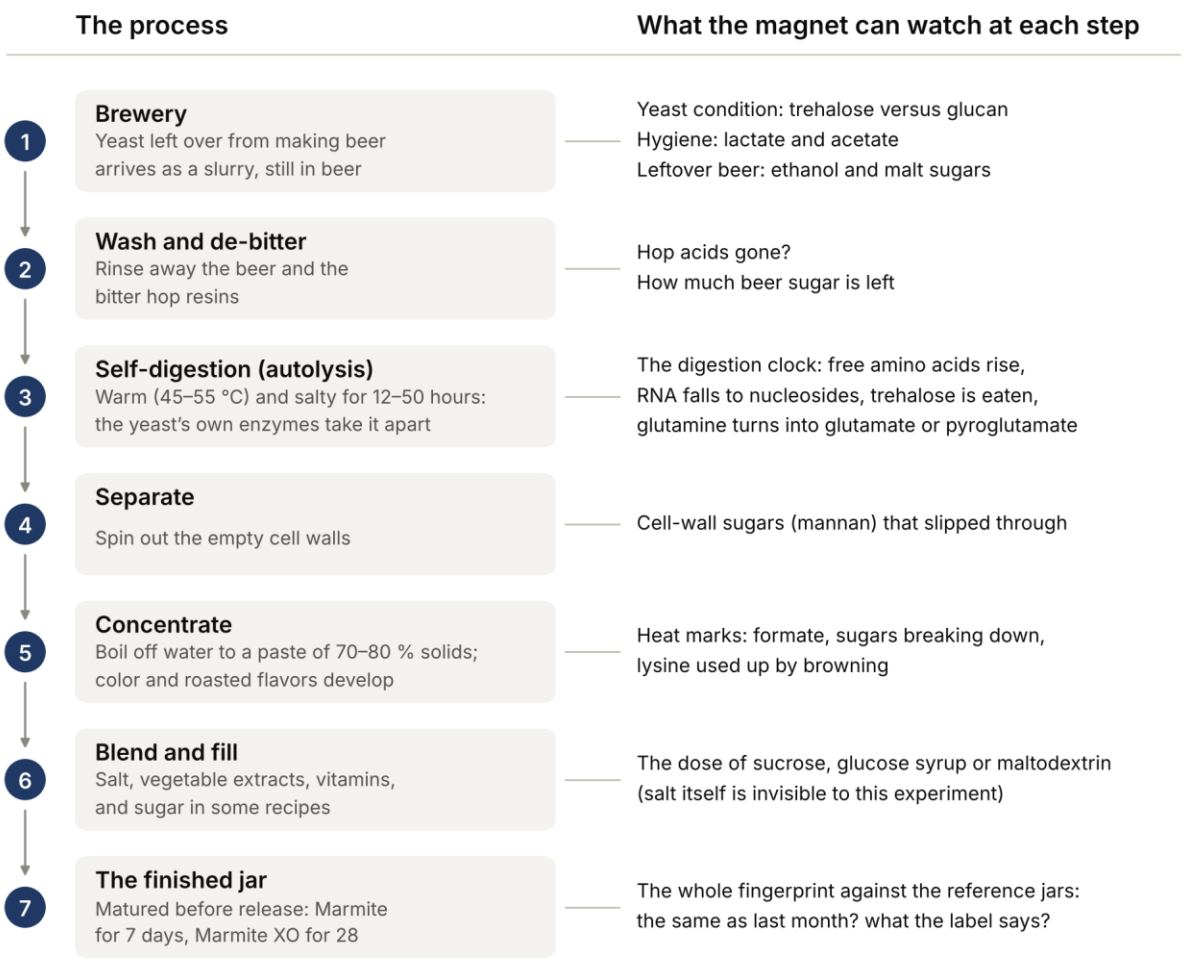


Figure 6. From brewery tank to jar. The generic process for a yeast-extract spread (left) and what an NMR spectrum could report at each step (right). The process is the one described in the industrial literature;[5,6] the manufacturers publish their own only in outline, and the right-hand column is a proposal, not something yet demonstrated on a production line.

As a lie detector

Because every ingredient leaves marks of its own, a spectrum can check a product against its label, or a delivery against its specification. Stretching an extract with cheap sugar or starch syrup shows up at once in the sugar stretch of Figure 3. Replacing yeast extract with acid-hydrolyzed vegetable protein removes the RNA fragments, the trehalose and the choline family and brings in levulinate and formate. Promite, which is entirely open about being a vegetable-protein product, shows what that looks like. Added flavor-enhancing nucleotides could be told from the yeast's own with the phosphorus experiment mentioned earlier. One thing the method cannot do, and it is better said plainly, is tell glutamate that came out of the yeast from glutamate that came out of a bag. The molecule is the same.

None of this need live in a research laboratory. Benchtop NMR instruments, not much bigger than a microwave oven and needing no liquid helium, can now sit beside a production line.[33] Their spectra are blurrier than those of Figure 1, but the large, well-separated signals that carry most of this story (alanine, trehalose, sucrose, the glucan hump, the choline family, acetate and formate) ought to survive the blurring, and a plan for testing that at 60 MHz is part of the technical paper.[1]

A word about status. Everything in this section is a proposal. It is what the five spectra suggest should work, and what experience with fruit juice shows does work elsewhere. It has not yet been demonstrated on a production run of yeast extract.

The honest small print

A short paper can afford to be blunt about its limits.

One jar of each. Everything here comes from a single jar, which is to say a single production batch, of each product. We cannot say how far one jar of Marmite differs from the next, so a difference between two products might in part be a difference between two batches. The contrasts that follow from the recipe (the sugar in the New Zealand jar, the vegetable-protein character of Promite) are safe enough, because the labels say the same. The contrasts that depend on the yeast and the process (trehalose in Vegemite against Marmite, and Marmite against Marmite XO) are exactly the kind that could move from batch to batch, and they need more jars before anyone leans on them.

Ratios, not grams. The numbers are molecule-for-molecule ratios within a jar, not amounts per 100 g, and comparing one jar with another through the alanine ruler is only as good as the assumption that the two hold similar amounts of free alanine. Converting the ratios into grams requires the weighed standard of Equation 3.

Names not yet confirmed the old-fashioned way. The molecules were identified by matching their signals against reference databases and the published literature. The classic proof, which is to add a pinch of the pure compound and watch its peak grow, has not yet been carried out for any of them.

No buffer. The samples were dissolved without controlling their acidity, which nudges some peaks sideways and makes one spectrum harder to compare with another. That is easily put right next time.

No tasting. All of the reasoning about taste comes from the scientific literature and from the ingredient labels, not from a panel.

Things this method will not see. The aroma molecules, most of the vitamins, the salt, and the difference between glutamate that was there all along and glutamate that was added.

The next steps follow directly: run the samples again, buffered and with a weighed standard; collect many batches of each product, ideally over a couple of years; add the phosphorus experiment to settle the nucleotide question; confirm the key identifications by adding the pure compounds; and bring in a tasting panel. Then this snapshot can become a survey.

References and further reading

1. Edwards J.C. Yeast-Extract Spreads: History, Raw Materials, Manufacture, Chemistry, Quality Control and the Role of Multinuclear NMR Spectroscopy in Composition Profiling, Consistency Monitoring, Adulteration Detection and Product Identity. Technical White Paper PNA-WP-2026-YE01, Version 1.2. Poughkeepsie, NY: Process NMR Associates, LLC; November 11, 2026.
2. Ferreira I.M.P.L.V.O., Pinho O., Vieira E., Tavarela J.G. Brewer's *Saccharomyces* yeast biomass: characteristics and potential applications. Trends Food Sci Technol 2010;21(2):77–84. https://doi.org/10.1016/j.tifs.2009.10.008

3. Grace's Guide to British Industrial History. Marmite Food Extract Co. https://www.gracesguide.co.uk/Marmite_Food_Extract_Co (accessed September 13–14, 2026).

4. Wikipedia contributors. Marmite. Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/wiki/Marmite (accessed September 13–14, 2026).

5. Tao Z., Yuan H., Liu M., Liu Q., Zhang S., Liu H., Jiang Y., Huang D., Wang T. Yeast extract: characteristics, production, applications and future perspectives. J Microbiol Biotechnol 2023;33(2):151–166. https://doi.org/10.4014/jmb.2207.07057

6. Takalloo Z., Nikkhah M., Nemati R., Jalilian N., Sajedi R.H. Autolysis, plasmolysis and enzymatic hydrolysis of baker's yeast (*Saccharomyces cerevisiae*): a comparative study. World J Microbiol Biotechnol 2020;36(5):68. https://doi.org/10.1007/s11274-020-02840-3

7. European Association for Specialty Yeast Products (EURASYP). What is yeast extract? https://www.yeastextract.info/yeast-extract/what-is-yeast-extract (accessed September 13–14, 2026).

8. Wills L. Treatment of "pernicious anaemia of pregnancy" and "tropical anaemia" with special reference to yeast extract as a curative agent. Br Med J 1931;1(3676):1059–1064. https://doi.org/10.1136/bmj.1.3676.1059

9. Bega Group. The VEGEMITE story. https://vegemite.com.au/heritage/the-vegemite-story/ (accessed September 13–14, 2026).

10. Wikipedia contributors. Vegemite. Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/wiki/Vegemite (accessed September 13–14, 2026).

11. Sanitarium Health Food Company. Marmite — Our story. https://marmite.co.nz/our-story/ (accessed September 13–14, 2026).

12. Wikipedia contributors. Marmite (New Zealand). Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/wiki/Marmite_(New_Zealand) (accessed September 13–14, 2026).

13. Australian Broadcasting Corporation. Marmite black-out ends in New Zealand. ABC News, 21 March 2013. https://www.abc.net.au/news/2013-03-21/an-marmite-returns-to-shelves-in-nz/4584816 (accessed September 13–14, 2026).

14. Wikipedia contributors. Promite. Wikipedia, The Free Encyclopedia. https://en.wikipedia.org/wiki/Promite (accessed September 13–14, 2026).

15. Woolworths Group. Promite Vegetable Extract Spread 290 g — product details, ingredients and nutrition information. https://www.woolworths.com.au/shop/productdetails/38930/promite-vegetable-extract-spread (accessed September 13–14, 2026).

16. Bharti S.K., Roy R. Quantitative ^{1}H NMR spectroscopy. TrAC Trends Anal Chem 2012;35:5–26. https://doi.org/10.1016/j.trac.2012.02.007

17. Open Food Facts. Marmite yeast extract, 250 g (barcode 50184453): ingredients and nutrition facts. https://world.openfoodfacts.org/product/50184453/marmite-yeast-extract (accessed September 13–14, 2026).

18. Unilever UK. Marmite XO is back. https://www.marmite.co.uk/marmite-xo-is-back.html (accessed September 13–14, 2026).

19. Open Food Facts. Vegemite, 560 g (barcode 9352042000342): ingredients. https://world.openfoodfacts.org/product/9352042000342/vegemite (accessed September 13–14, 2026).

20. Sanitarium Health Food Company. Marmite — Frequently asked questions. https://marmite.co.nz/faqs/ (accessed September 13–14, 2026).

21. François J., Parrou J.L. Reserve carbohydrates metabolism in the yeast *Saccharomyces cerevisiae*. FEMS Microbiol Rev 2001;25(1):125–145. https://doi.org/10.1111/j.1574-6976.2001.tb00574.x

22. Somani A., Bealin-Kelly F., Axcell B., Smart K.A. Impact of storage temperature on lager brewing yeast viability, glycogen, trehalose, and fatty acid content. J Am Soc Brew Chem 2012;70(2):123–130. https://doi.org/10.1094/asbcj-2012-0427-01

23. Nwaka S., Holzer H. Molecular biology of trehalose and the trehalases in the yeast *Saccharomyces cerevisiae*. In: Progress in Nucleic Acid Research and Molecular Biology, vol. 58. San Diego: Academic Press; 1997. p. 197–237. https://doi.org/10.1016/s0079-6603(08)60037-9

24. Wang M-L., Lin H-J., Lee M-H., Choong Y-M. A rapid method for direct determination of levulinic acid in soy sauce. J Food Drug Anal 1999;7(2):133–138. https://doi.org/10.38212/2224-6614.2873

25. Yamaguchi S. The synergistic taste effect of monosodium glutamate and disodium 5′-inosinate. J Food Sci 1967;32(4):473–478. https://doi.org/10.1111/j.1365-2621.1967.tb09715.x

26. Breslin P.A.S., Beauchamp G.K. Salt enhances flavour by suppressing bitterness. Nature 1997;387(6633):563. https://doi.org/10.1038/42388

27. Keast R.S.J., Breslin P.A.S. An overview of binary taste–taste interactions. Food Qual Prefer 2003;14(2):111–124. https://doi.org/10.1016/s0950-3293(02)00110-6

28. Higashiyama T. Novel functions and applications of trehalose. Pure Appl Chem 2002;74(7):1263–1269. https://doi.org/10.1351/pac200274071263

29. Sinopoli D.A., Lawless H.T. Taste properties of potassium chloride alone and in mixtures with sodium chloride using a check-all-that-apply method. J Food Sci 2012;77(9):S319–S322. https://doi.org/10.1111/j.1750-3841.2012.02862.x

30. Liu J., Song H., Liu Y., Li P., Yao J., Xiong J. Discovery of kokumi peptide from yeast extract by LC-Q-TOF-MS/MS and sensomics approach. J Sci Food Agric 2015;95(15):3183–3194. https://doi.org/10.1002/jsfa.7058

31. Spraul M., Schütz B., Rinke P., Koswig S., Humpfer E., Schäfer H., Mörtter M., Fang F., Marx U.C., Minoja A. NMR-based multi parametric quality control of fruit juices: SGF profiling. Nutrients 2009;1(2):148–155. https://doi.org/10.3390/nu1020148

32. Combe M., Isaac K.S., Potter G., Sokolenko S. NMR metabolomics of plant and yeast-based hydrolysates for cell culture media applications — a comprehensive assessment. Curr Res Food Sci 2024;9:100855. https://doi.org/10.1016/j.crfs.2024.100855

33. Grootveld M., Percival B., Gibson M., Osman Y., Edgar M., Molinari M., Mather M.L., Casanova F., Wilson P.B. Progress in low-field benchtop NMR spectroscopy in chemical and biochemical analysis. Anal Chim Acta 2019;1067:11–30. https://doi.org/10.1016/j.aca.2019.02.026

The takeaway

Yeast extract is brewery yeast that has been made to digest itself, then strained and boiled down. Vegetable extract is plant protein broken down with acid. In a jar the two can look much alike. A 300 MHz NMR spectrum of a dab of each spread, dissolved in heavy water, tells them apart at a glance and goes on to name several dozen of their constituents.

The four yeast-based jars share a core of free amino acids, peptides, the choline family, glycerol, small acids and RNA fragments. In the single jars we measured they differ most in their sugars. British Marmite keeps a starch-like glucan and has lost most of its trehalose, and the 28-day Marmite XO has lost more. Vegemite is the reverse. New Zealand Marmite is an extract of the Vegemite kind under a blanket of table sugar. Promite is, on this evidence, acid-digested vegetable protein and sugar, with no yeast fingerprint that we could detect. Those differences line up with the way each product appears to tame its own bitterness, with salt in Britain and with sweetness in Australasia, although that link rests on published taste science and not yet on a tasting panel.

The same measurement could serve a manufacturer in three ways: as a fingerprint of the whole product, as a set of gauges on the process from brewery yeast to finished jar, and as a check on authenticity. Paired with trained tasters, it could show which molecules drive which sensations. All of it rests so far on one jar of each product, measured as ratios and not yet in grams, which is why the last word belongs to the to-do list. In the meantime, the toast is getting cold.