PLAIN-LANGUAGE EDITION · THE SHORT VERSION OF WHITE PAPER V2.2

Grate Expectations

What a magnet found in 84 cheeses and 40 containers of grated Parmesan and Romano, told in plain English

A condensed, informal companion to the white paper "Paired ^{1}H NMR Screening of Retail Grated Cheese", version 2.2

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November 15, 2026 · Version 1.1

Abstract

Grated cheese is cheese with its identity papers shredded: once a wedge has become a powder, nobody can judge it by eye. This report is the short, informal version of a technical white paper in which 84 cheese products were examined by proton nuclear magnetic resonance (^{1}H NMR) spectroscopy at 300 MHz. Each product was extracted twice, once with chloroform to collect the fat and once with heavy water to collect the small water-soluble molecules, so that every product was described by two spectra that answer two different questions: is the fat milk fat, and is the water-soluble chemistry that of a cheese that was ripened?

Reference cheeses from Parmigiano Reggiano to plant-based slices behaved as their types predict. Of 40 retail grated Parmesan and Romano products, 16 were consistent in both extracts with grated hard cheese made from milk fat. Twenty-two were flagged for a fat estimated at 43 to 68% non-milk fat (median 51%, each about ± 8 percentage points), with a composition consistent with a palm-type fat, and 21 of these had a water-soluble profile resembling processed cheese: few free amino acids, together with citrate, sugars and emulsified fat. Three products fit neither pattern. These are the results of a screening study. They identify neither the oil, the manufacturing route, the proportion of cheese nor its age, and cellulose is invisible to the method.

Along the way the report explains how cheese is made and ripened, what the terms on a label mean, and, with nothing harder than division, how the numbers are obtained. It closes with what such a measurement could do outside a detective story: quality control in a cheese plant, the tracking of fermentation and aging from vat to wheel, and, in partnership with sensory panels, an understanding of which molecules make a cheese taste the way it does.

Keywords: *cheese; grated Parmesan; Romano; NMR spectroscopy; milk fat; butyrate; vegetable fat; processed cheese; ripening; free amino acids; quality control; sensory analysis; food authenticity*

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1. Why Would Anyone Put Cheese in a Magnet?

A wedge of Parmigiano Reggiano has a face. The rind is stamped with its name, the paste is the color of straw, there are white flecks where crystals have formed, and it can be smelled from across the kitchen. Grate it, and the face is gone. What is left is a pale, free-flowing powder that looks exactly like every other pale, free-flowing powder, and that is the whole problem.

The expensive ingredient in a hard grating cheese is not milk. It is time. A wheel of Parmigiano Reggiano sits in a ripening room for at least twelve months, Grana Padano for nine, an American Parmesan for at least ten, and all the while somebody is paying for the milk, the shelf, the labor and the water that slowly evaporates away[1–3]. A powder that skips the wait is much cheaper to make, and once it is in a shaker nobody can tell by looking.

This is not a hypothetical worry. An enforcement action brought in the United States between 2012 and 2016, and the product testing reported in the press at the time, showed that products sold as 100% grated Parmesan had been stretched in several ways: with cheaper cheese, with cheese substitutes, and with more powdered cellulose than the job of keeping a powder from clumping requires[4]. The headlines went for the wood-pulp angle. Cellulose is plant fiber and a permitted anticaking agent, and it will come up again later, mostly so that we can explain why our method cannot see it.

So we did what a laboratory full of NMR spectrometers naturally does: we went cheese shopping. Eighty-four products came back. Forty-two were cheeses and cheese-like products whose identity was not in doubt, from Parmigiano Reggiano and Pecorino Romano through mozzarella and American slices to plant-based slices that have never met a cow. Forty were retail grated products labeled Parmesan, Romano, Pecorino Romano or a blend of these, and their composition was the question. (The last two had muddled paperwork and were set aside.) From each product two small extracts were made, one of the fat and one of the water-soluble molecules, and each extract spent a few minutes in a 300 MHz NMR magnet.

What follows is the short version of a white paper that runs to about a hundred pages[5]. It keeps the story and the main numbers, leaves most of the statistics behind, and tries to explain the chemistry in English that does not require a lab coat. One caution belongs at the start, because it colors everything else: this was a **screening study**. One laboratory, one extraction per product, and no parallel testing by an official reference method. A screen is a metal detector, not an excavation. When it beeps, something is worth digging for. It does not say what will be found, or who buried it.

2. Cheese 101: Milk, Microbes, Salt and Time

Cheese is what happens when the most perishable food on the farm is persuaded to keep. The recipe has four ingredients (milk, microbes, salt and time) and about a thousand variations, but the plot is always the same[1,6].

First, bacteria called starter cultures eat the milk sugar, lactose, and turn it into lactic acid. Second, an enzyme preparation called rennet clips the main milk protein, casein, so that it knits into a soft gel, the curd, which traps the fat. The curd is cut, stirred, sometimes cooked, and drained of its watery whey. What stays behind is pressed into shape and salted. Up to this point every cheese is a young cheese: mild, milky and a little rubbery. Fresh mozzarella stops about here.

Everything interesting happens next, slowly, in the dark. Cheese scientists sort the chemistry of ripening into three plot lines[7,8]. In **glycolysis**, the last of the sugar disappears, and the lactic acid itself may be eaten by something else. In **proteolysis**, enzymes chop the long casein chains into shorter pieces and finally into single amino acids, the building bricks of protein, which is where much of the savory depth of an old cheese comes from. In **lipolysis**, enzymes snip fatty acids off the fat, which is where the peppery bite of a Romano or a blue cheese comes from. Give a cheese a year and it is a different substance: the sugar is gone, free amino acids are everywhere, and in the oldest cheeses the amino acid tyrosine has grown into little crunchy crystals[2,9].

The 84 products were chosen to cover as much of this territory as a shopping trip allows. They are sorted into families in Table 1, each with the feature that matters most for what comes later. The reference families are the yardsticks. The forty grated products at the bottom of the table are what the yardsticks were for.

Table 1. The cast: the cheese families in the study, how each is made, and the chemical feature to watch for. Numbers in parentheses are the number of products.

Family	In this study	Made how, in one breath	What to watch for
Grana type	Parmigiano Reggiano, Grana Padano, Piave Vecchio, domestic Parmesan (6)	Cooked, pressed, brined, then aged from nine months to more than two years	Plenty of free amino acids; no sugar and no citrate left; ordinary cow's-milk fat
Sheep's milk	Pecorino Romano, Manchego, a sheep's-milk table cheese (4)	Sheep's milk; Pecorino Romano is set with lamb rennet paste, which carries a fat-splitting enzyme	The sharp, lipolyzed character of Pecorino Romano; a fat with its own fingerprint
Alpine	Emmental, Gruyère, aged and fresh Asiago (4)	Cooked curd; in Emmental a second fermentation blows the holes	In Emmental: propionate and acetate up, lactate down
Gouda and Cheddar type	Young, aged and extra-aged Gouda, smoked Gouda, Mimolette, an Irish Cheddar type (7)	Washed or cheddared curd, with starter bacteria that also eat citrate; up to 26 months	Citrate gone early; plenty of amino acids once aged
Blue and brined	Blue Stilton, a buffalo-milk blue, feta (3)	Blue mold grown through the paste, or ripening in brine	Blue cheese is the most lipolyzed of all, and its mold eats the lactate
Young and fresh	Low-moisture and fresh mozzarella, Monterey Jack, Muenster (5)	Days to weeks old	Hardly any free amino acids; sugars and citrate still present
Processed	American slices and singles (4)	Natural cheese melted with emulsifying salts, often with other dairy solids	Hardly any amino acids; citrate and lactose; fat that follows the water
Declared vegetable-fat products	Grated "cheese products", an imitation topping, a blend that declares palm oil, a prepared cheese loaf (6)	A casein or cheese base with vegetable fat and emulsifying salts, as their labels say	Milk-fat markers low or missing; vegetable-oil markers raised
Plant-based	Slices and a snack round (3)	Coconut oil and starch; no dairy at all	No dairy marker of any kind: the built-in blank
The question	Retail grated Parmesan, Romano, Pecorino Romano and blends (40)	Labeled as grated hard cheese	To be found out

3. Talking the Talk: A Field Guide to Label Language

Cheese labels are written in a dialect of their own, part Italian and part food law. A few terms are worth learning before any data appear, because the whole story turns on the difference between a cheese, a cheese product, and something that merely keeps cheese company.

Start with the names. **Parmigiano Reggiano** is a protected name: the cheese must come from a defined corner of northern Italy (Parma, Reggio Emilia, Modena and parts of Bologna and Mantua) and must be aged for at least twelve months[2]. **Parmesan**, in the United States, is a looser word with a legal definition of its own: a cow's-milk cheese cured for at least ten months, with no more than 32% moisture and at least 32% milk fat in its solids[3]. **Romano** may be made from cow's, sheep's or goat's milk and must be cured for at least five months; only the sheep's-milk version may be called **Pecorino Romano** (*pecora* is Italian for sheep)[10]. Legal recipes of this kind are called standards of identity. There is one for grated cheese too, and it is short: a grated cheese must be made from the cheese it is named for, and the only

permitted extras are something to stop mold, something to stop clumping, and spices or flavorings that do not imitate cheese[11].

Anything that contains vegetable fat, emulsifying salts or an unripened base therefore sits outside those definitions, whatever the front of the package suggests. The industry has a graded vocabulary for such things, collected in Table 2. The word to watch is “product”.

Table 2. A short glossary of cheese-making and cheese-labeling terms used in this report.

Term	What it means in plain English
Curd and whey	The solid gel and the watery liquid into which milk separates. Cheese is the curd.
Starter culture	The bacteria added to turn lactose into lactic acid. Thermophilic starters like it hot (Parmesan, mozzarella, Swiss types); mesophilic starters prefer room temperature (Gouda, Cheddar).
Rennet	The enzyme preparation that sets milk into curd. The lamb rennet paste used for Pecorino Romano also carries a lipase.
Ripening (aging, curing)	The weeks, months or years in which enzymes and microbes remodel a young cheese. The French word for the craft is *affinage*.
Lipase, lipolysis	An enzyme that clips fatty acids off fat, and the result. In moderation, piquant; in excess, rancid.
Grana	Italian for “grainy”: the family of hard, cooked, long-aged grating cheeses.
PDO	Protected designation of origin: a European legal protection that ties a name to a place and a method. Parmigiano Reggiano, Grana Padano and Pecorino Romano are PDO cheeses.
Pasta filata	“Spun paste”: curd that is heated and stretched, as for mozzarella.
Eyes	The holes in a Swiss-type cheese, blown by carbon dioxide from a second fermentation.
Standard of identity	The legal recipe a food must follow in order to use a name such as Parmesan or Romano.
Pasteurized process cheese	Natural cheese melted and blended with emulsifying salts. The familiar American slice.
Emulsifying salts	Sodium citrates and sodium phosphates. They pull calcium off the protein, so that fat and water stay blended when the cheese melts.
Cheese food, cheese spread, cheese product	Process cheese with increasing proportions of other things, such as whey, milk solids and water. “Cheese product” is the loosest of these names.
Imitation or analogue cheese	A cheese-like material built from milk protein (casein), vegetable fat and emulsifying salts, with little or no natural cheese.
Enzyme-modified cheese	Cheese treated with enzymes to make a concentrated flavor paste, which is used to flavor processed and imitation products.
Plant-based cheese alternative	No dairy at all. Typically coconut oil and starch.
Vegetable fat, vegetable oil	Fat from plants. In cheese-like products it is usually palm oil, a fraction of palm oil, or coconut oil, all of which are solid enough at room temperature to stand in for butterfat.
Anticaking agent	Something added to grated cheese so that it pours. Usually powdered cellulose, which is purified plant fiber.
Antimycotic	A mold inhibitor, in grated cheese usually potassium sorbate.
Milk fat (butterfat)	The natural fat of milk, and the hero of the next few sections.

“Vegetable” fat, and a word about yeast extract

Two kinds of ingredient do most of the work when a product has to look and taste like cheese without being all cheese. The first is vegetable fat. Butterfat is expensive; palm oil, its harder fractions and coconut oil are not, and they are firm enough at room temperature to pass for it in a slice or a shaker[12–14].

The second is savory flavoring, and here the label terms to know are enzyme-modified cheese, hydrolyzed vegetable protein and yeast extract. Yeast extract is exactly what it sounds like. Yeast cells, often left over from brewing, are broken open, typically by letting their own enzymes digest them; the cell walls are removed, and the soluble contents are concentrated into a paste or powder that is rich in free amino acids, small peptides and nucleotides[15,16]. It delivers in an afternoon the brothy, savory note that a hard cheese earns over a year of ripening. Hydrolyzed vegetable protein reaches a similar place by breaking plant protein down into its amino acids.

These flavorings are described here because they belong to the vocabulary of the subject, not because they were found. No product in this study was tested for yeast extract or hydrolyzed protein, and nothing in the results depends on either.

4. How to Interview a Cheese

Nuclear magnetic resonance, NMR for short, is the same physics as a hospital MRI scanner, pointed at a test tube instead of a knee. The nuclei of hydrogen atoms behave like tiny compass needles. In a strong magnet they can be made to ring with a pulse of radio waves, and each one rings at a pitch that depends on its chemical neighborhood: a hydrogen at the end of a fatty chain sounds different from one beside a double bond or one on a sugar. The instrument records all the ringing at once and sorts it by pitch. The result is a spectrum, a row of peaks in which the position of a peak says what kind of hydrogen it is and the area under the peak says how many of them there are.

That last property is the useful one. An NMR spectrometer is, in the end, a machine for counting hydrogen atoms, and counting is all the arithmetic this report needs:

$$\text{amount of a molecule} = \text{a constant} \times (\text{area of its peak} \div \text{number of hydrogens in the peak}) \tag{1}$$

A methyl group, CH_3, has three hydrogens, so its peak area is divided by three. A methylene group, CH_2, has two. After that it is a matter of comparing one count with another. The horizontal scale of a spectrum is marked in “ppm”, parts per million, which is nothing more than a ruler for position. By long tradition it runs backward, with the high numbers on the left. Chemists stopped apologizing for this some time ago.

Fat does not dissolve in water, and the small molecules of fermentation and ripening do not dissolve in fat, so each cheese was interviewed twice (Figure 1). One portion was extracted with chloroform, which takes up the fat. Another extract was made with heavy water, which takes up the lactic acid, the free amino acids, the sugars and the other water-loving molecules. Both solvents are the “deuterated” kind, in which ordinary hydrogen has been swapped for its heavier twin so that the solvent stays quiet while

the cheese does the talking. Our magnet runs at 300 MHz, which makes it a workhorse and not a racehorse; nothing described here needs an exotic instrument.

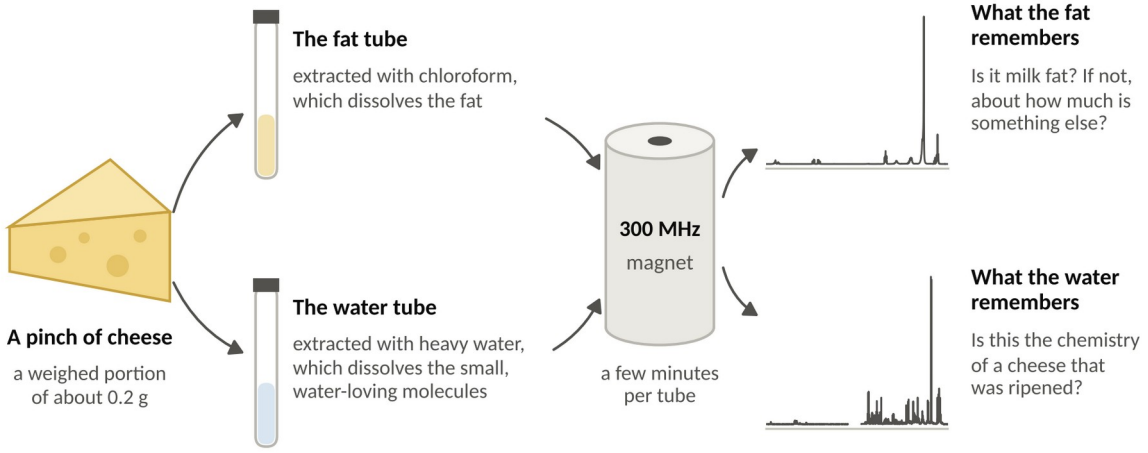

Figure 1. Two tubes, one magnet. Each product gave a fat extract and a water extract, and each extract gave a spectrum that answers a different question. The two small spectra are measured ones: the average fat spectrum of the milk-fat reference cheeses (top) and the water extract of an 18-month domestic Parmesan (bottom).

Two housekeeping points will matter later. No measured amount of a reference compound was added to the tubes, so every result is a ratio within one spectrum: so many butyrate chains per hundred fatty chains, or so much amino-acid signal per ten thousand units of total signal. Ratios are sturdy things, since they do not care how big the pinch of cheese was, but they are not the same as grams per hundred grams. And two components of a cheese never reach either tube: the protein itself, and any insoluble filler such as cellulose. Hold that thought.

5. Tube One: What the Fat Remembers

A fat molecule is a small coat hanger with three long garments on it. The hanger is glycerol; the garments are fatty acids, chains of carbon atoms studded with hydrogen (Figure 2). Fats differ in which chains they carry: long or short, straight (saturated) or kinked by double bonds (unsaturated). Olive oil is mostly one kinked chain. Palm oil is about half straight chains and half kinked ones. Milk fat is the eccentric of the family, with hundreds of different chains, and one of them is found in almost no other food fat.

That chain is butyrate, the fatty acid with only four carbons. It is named after butter (*butyrum* in Latin), it gives rancid butter its smell when it escapes, and in the fat of cow's milk it makes up about one chain in every eleven[17,18]. Vegetable oils, lard and tallow have essentially none. Better still, the hydrogens at the end of a butyrate chain ring at a slightly different pitch from the ends of all the longer chains, so they stand apart in the spectrum as a small flag of their own[19,20].

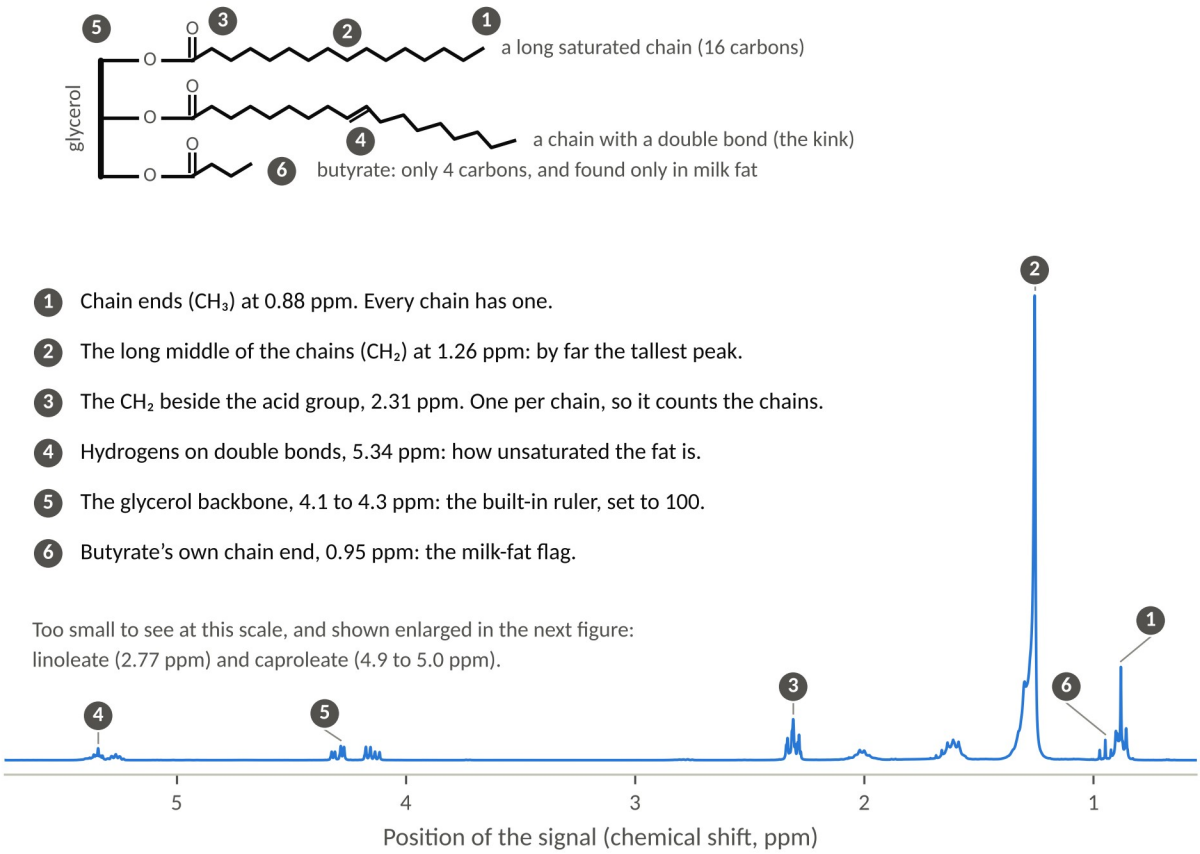

Figure 2. How to read a fat spectrum. Top: a cartoon of one milk-fat molecule, a glycerol backbone carrying three fatty chains. Bottom: the measured spectrum, averaged over the 24 milk-fat reference cheeses and drawn at full scale. The numbered labels connect parts of the molecule to their peaks.

Counting butyrate takes two peaks and one line of arithmetic. Butyrate's chain end is a CH_3 group, three hydrogens. Every chain of any kind has a CH_2 group next to its acid end, two hydrogens, so that peak counts the chains. Therefore:

$$\text{butyrate chains per 100 chains} = 100 \times (\text{area of the butyrate flag} \div 3) \div (\text{area of the chain-counting peak} \div 2) \quad (2)$$

In the 24 cow's-milk reference cheeses that showed no sign of fat breakdown, the answer was 9.1 butyrate chains per hundred, with a spread (one standard deviation) of only 0.5. (The white paper measures the flag by fitting its three lines, which keeps a neighboring signal out of the count.) That is a narrow target. Parmigiano Reggiano, young Gouda, mozzarella and American slices all hit it, because however differently those cheeses are made, the cow supplied the same fat.

Three more features complete the description, and each can be seen in Figure 3. **Caproleate** is a rare ten-carbon chain with a double bond at its very tip; like butyrate it belongs to milk fat, and it averaged 0.50 chains per hundred. **Linoleate**, the classic polyunsaturated chain of vegetable oils, is scarce in milk fat at about 1.8 per hundred. And the **average chain length** of milk fat is short, 14.2 carbons, because of

all those small chains; palm oil averages about 17.5. Add everything up and milk fat comes out roughly 70% saturated, 28% monounsaturated and 2.5% polyunsaturated.

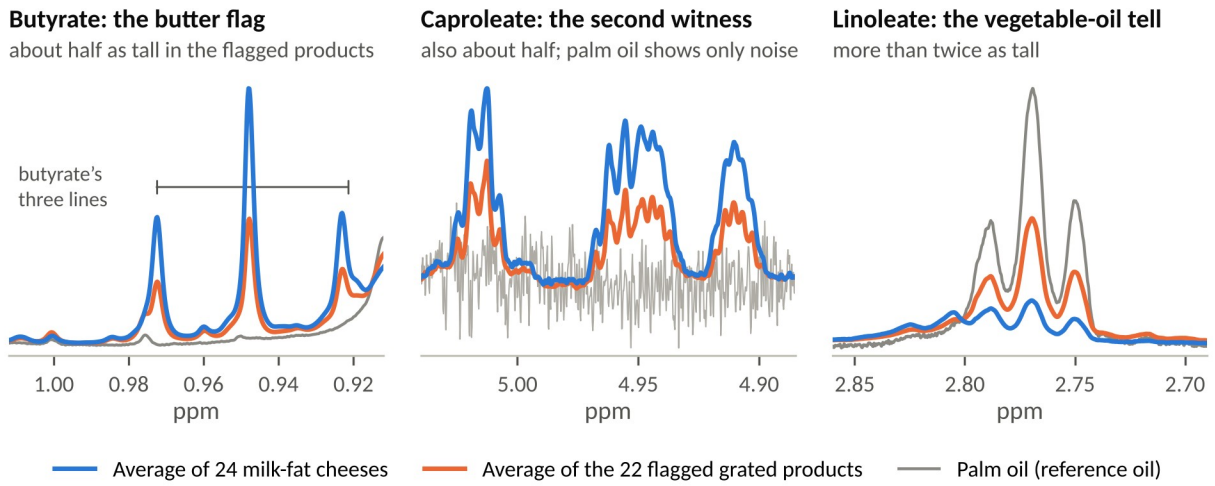

Figure 3. Three small windows of the fat spectrum, enlarged. Butyrate and caproleate are the milk-fat markers; linoleate is the vegetable-oil marker. Each window has its own vertical scale, set by its tallest signal, and all traces are on the same footing (glycerol = 100). The rise at the right-hand edge of the butyrate window is the flank of the large chain-end peak next door. In the caproleate window each trace is drawn above a straight local baseline.

Now plot every product by its two most telling numbers, butyrate across and linoleate up, and the collection sorts itself (Figure 4). Nearly every cheese bought as a block, a wedge or a slice sits in one tight cloud at the lower right: plenty of butyrate, hardly any linoleate. The plant-based products sit at the far left with no butyrate at all. The products that state vegetable oil on their labels are spread across the space between, and so are 22 of the 40 products sold as grated Parmesan and Romano. They cluster about halfway along a straight line that runs from milk fat toward a fat with no butyrate and much more linoleate. That line is simply what dilution looks like.

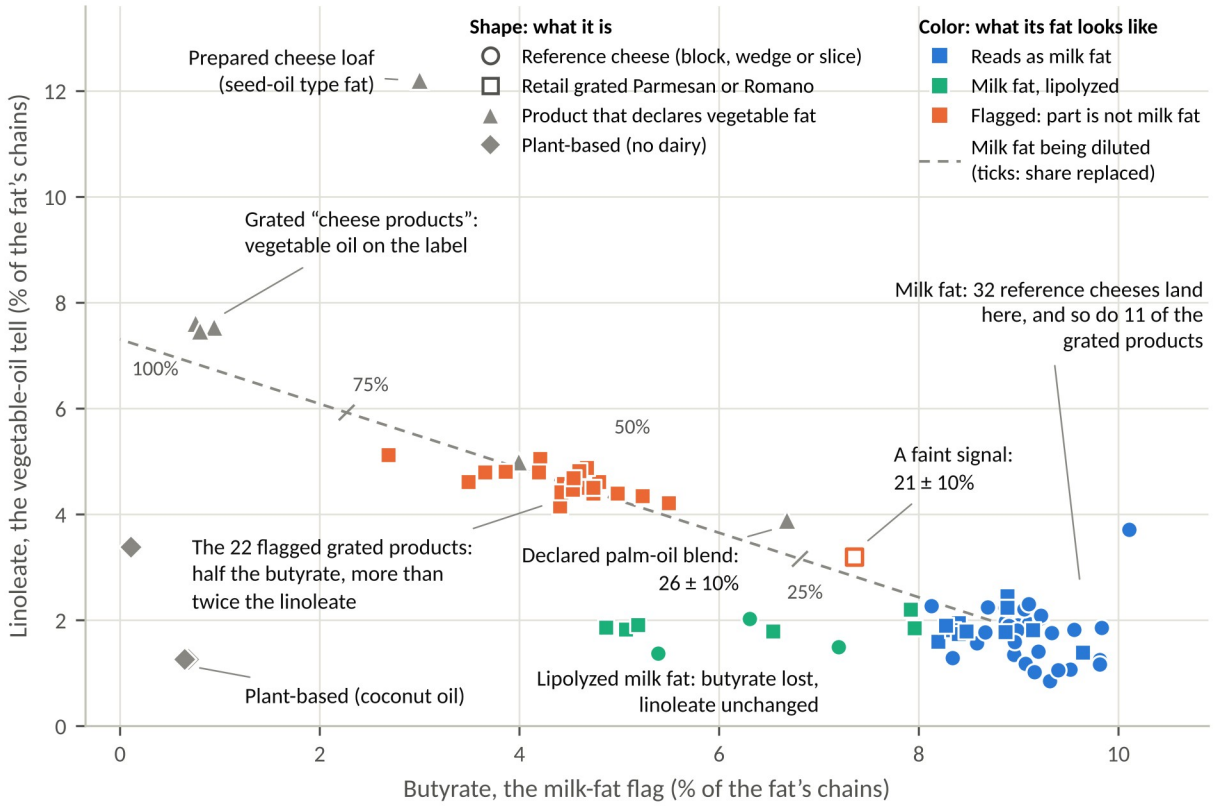

Figure 4. The milk-fat map: all 84 products by butyrate and linoleate. The dashed line shows where milk fat goes as it is diluted with the replacing fat that was calculated for the flagged products; the ticks mark the share replaced. One product, drawn as an open square, gave only a faint indication.

The fat remembers more than its species. Sheep's milk gives a fat with its own proportions, and milk from animals on pasture carries more of certain minor chains (conjugated linoleic acid and the omega-3 family)[21]. The two imported grated Pecorino Romano products in the test set matched the Pecorino Romano blocks on exactly those minor chains, which is a pleasing thing to be able to say about a powder.

One complication has to be faced before any verdicts, because it is the classic way to get this wrong. Cheeses ripened with fat-splitting enzymes, Romano and the blues above all, lose butyrate for a perfectly innocent reason. Lipases clip fatty acids off the glycerol hanger, butyrate tends to go first, and once it is free it leaves the fat extract: it prefers water and it evaporates[22,23]. A cheese like that shows a low butyrate flag while its fat is still entirely milk fat. In Figure 4 such products slide to the left along the bottom of the chart: butyrate down, linoleate unmoved. Telling this apart from dilution is the job of a second witness, and we will call it in Section 7.

6. Tube Two: What the Water Remembers

The water extract is the cheese's diary. Whatever the microbes ate and whatever the enzymes released ends up as small, water-loving molecules, and each of them has its peaks (Figure 5). Lactate, the lactic acid of fermentation, is the tall one. The free amino acids released from protein during ripening spread

across the spectrum like a forest. Citrate, sugars and the short acids of special fermentations each have their own corner.

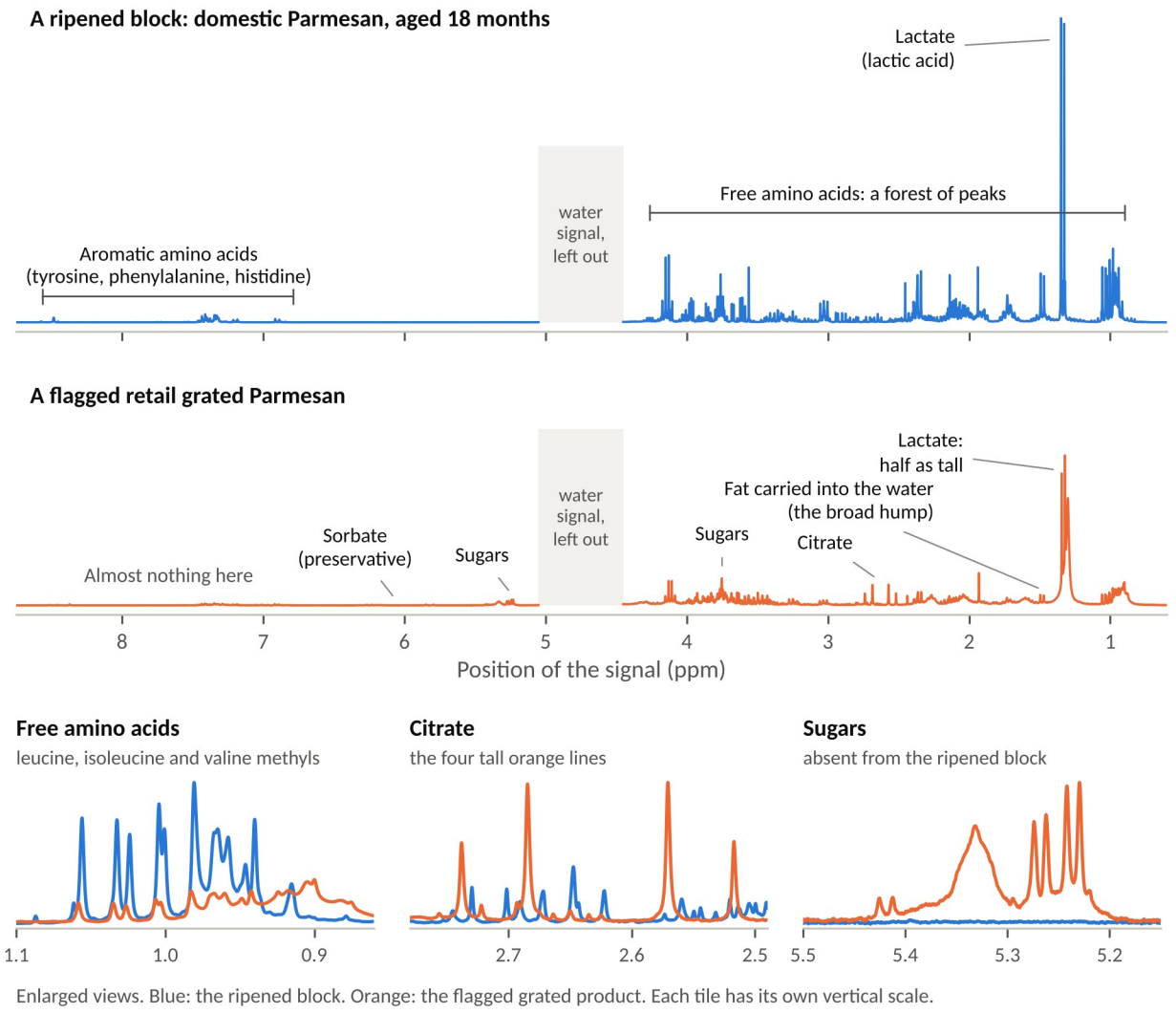

Figure 5. How to read a water spectrum. Top: an 18-month domestic Parmesan. Middle: one of the flagged retail grated products, drawn on the same vertical scale. Bottom: three regions enlarged. The broad swelling at the right-hand end of the amino-acid tile is fat that was carried into the water extract.

Because no reference compound was weighed into the tubes, the amounts are expressed as an index, the share of the whole spectrum that belongs to one kind of molecule:

$$\text{index of a molecule} = 10{,}000 \times (\text{area of its peak} \div \text{number of hydrogens}) \div (\text{area of the whole spectrum}) \tag{3}$$

The free amino-acid index used throughout this report is built on the methyl groups of three amino acids (leucine, isoleucine and valine) that share a clear patch of the spectrum. Four other entries in the diary matter most, and Figure 6 sets them out family by family.

Sugar is the first thing to go. In a Grana-type cheese the lactose is gone within days and the last traces of its fragments within weeks, so a ripened cheese has essentially no free sugar: an index of 2 to 7, against roughly 260 to 650 in young cheeses, processed slices and the declared cheese products. **Citrate**, a natural component of milk, is used up during ripening too, and it reads zero in the Grana, sheep's-milk and alpine families. It is still there in a young cheese, and it comes back in processed cheese, where sodium citrate is added on purpose as an emulsifying salt[13,24]. **Free amino acids** run the other way: next to nothing in a young cheese (an index of 1 to 2), about 45 in the Grana family. And **fat that shows up in the water** is the calling card of emulsifying salts, which loosen the protein so that it wraps the fat into droplets too fine to settle. The index for this dispersed fat was about 2,000 in the processed slices and 50 to 240 in the Grana, sheep's-milk, alpine and Gouda families.

n	Cheeses of known type	Free amino acids made by ripening	Lactate made by fermentation	Citrate used up, or added	Free sugars used up by ripening	Fat in the water a sign of emulsifying
6	Grana type: Parmigiano Reggiano, Grana Padano, Parmesan	45	368	0.0	2.2	238
4	Sheep's milk: Pecorino Romano, Manchego	36	502	0.0	7.0	51
4	Alpine: Emmental, Gruyère, Asiago	46	249	0.0	2.5	53
7	Gouda and Cheddar type	36	316	4.7	3.8	104
3	Blue and brined: Stilton, buffalo blue, feta	27	135	0.0	1.4	374
5	Young and fresh: mozzarella, Jack, Muenster	1.7	679	42	257	69
4	Processed slices and singles	1.5	229	66	287	1991
6	Products that declare vegetable fat	0.7	87	42	653	468
	Retail grated Parmesan and Romano					
11	A: milk fat, ripened profile	35	449	0.0	4.5	369
5	B: lipolyzed milk fat, ripened profile	34	376	0.0	2.6	352
21	C: flagged fat, processed-type profile	9.7	211	50	69	1714

Figure 6. Who has what in the water tube: the middle (median) value of five indices in each family. Darker means more, column by column. The plant-based products are left out, because an added propionate signal falls inside the amino-acid window and inflates their index; for the same reason the alpine value, which includes Emmental, is slightly overstated.

Read across the rows of Figure 6 and each family has a face. The **Grana** cheeses are the amino-acid champions, with their sugar and citrate long gone. The **sheep's-milk** cheeses run high in lactate, and Pecorino Romano shows the work of its lipase. Among the **alpine** cheeses, Emmental has traded its lactate for propionate and acetate (Section 9 shows the spectrum), while a fresh Asiago a few weeks old has barely begun to release amino acids. The **Gouda and Cheddar** family keeps a trace of citrate and, once aged, comes close to the Grana cheeses for amino acids. In the **blue** cheeses the mold has eaten most of the lactate, and in the buffalo-milk blue it has broken down a good deal of the fat as well. The **young and fresh** cheeses are the mirror image of the old ones: the most lactate of all, sugar and citrate still on the table, and almost no amino acids. **Processed slices** share that youthful profile and add the marks of the kettle, which are citrate, lactose from added dairy solids and fat emulsified into the water;

their fat itself is perfectly good milk fat. The **declared vegetable-fat products** look like processed cheese with more sugar and less milk fat, except for the one blend built on real Parmigiano Reggiano, which keeps a largely ripened profile. And the **plant-based** products show no dairy chemistry at all: a coconut-type fat with the shortest chains in the study, and a large starch signal.

A few supporting characters deserve a mention. **Sorbate**, a permitted mold inhibitor, appeared in 33 of the 40 retail grated products and in none of the block cheeses of the ripened families. It is evidence of nothing except that the powder came out of a retail container, and it was ignored. **Free butyrate**, the fugitive from the fat tube, turns up here: it was strongest in the most lipolyzed grated products and in Parmigiano Reggiano. And with one extra trick the water tube will even count **calcium**. A few drops of EDTA, a molecule that grips metals, turn the dissolved calcium and magnesium into complexes with sharp peaks of their own. On a provisional scale, the ripened reference cheeses released 240 to 600 mg of calcium per 100 g into the water, a processed single 116 and a fresh mozzarella 70. Emulsifying salts lock calcium away, which is how they work, so low soluble calcium is one more mark of a processed base[25,26].

7. The Forty

With the yardsticks in place, the 40 retail grated products can be read. Most were shelf-stable products in shaker containers, a few were refrigerated, one was grated in the store from a domestic block, and two were imported grated Pecorino Romano. They are identified here only by type, as they are in the white paper.

The fat tube: two witnesses

Twenty-two of the forty were flagged. Their butyrate was about half of what milk fat carries, their linoleate was more than twice as high, and their average chain length was longer. If the missing butyrate is read as dilution, the arithmetic is a single line:

$$\text{share of the fat that is not milk fat} \approx 100 \times (1 - \text{butyrate found} \div 9.1) \tag{4}$$

A product with 4.5 butyrate chains per hundred, for example, comes out at 100 × (1 − 4.5 ÷ 9.1), or about 50%. The white paper's version of the sum is a little more careful than this, but not different in kind. Across the 22 flagged products the estimates ran from 43 to 68% of the fat's chains, with a middle value of 51%, and each is good to about ± 8 percentage points (Figure 7). By weight that is roughly 46 to 70%. The ± 8 covers the natural variation of milk fat and the variation seen between lots. It does not cover everything that could go wrong in an extraction, so the true uncertainty is somewhat larger.

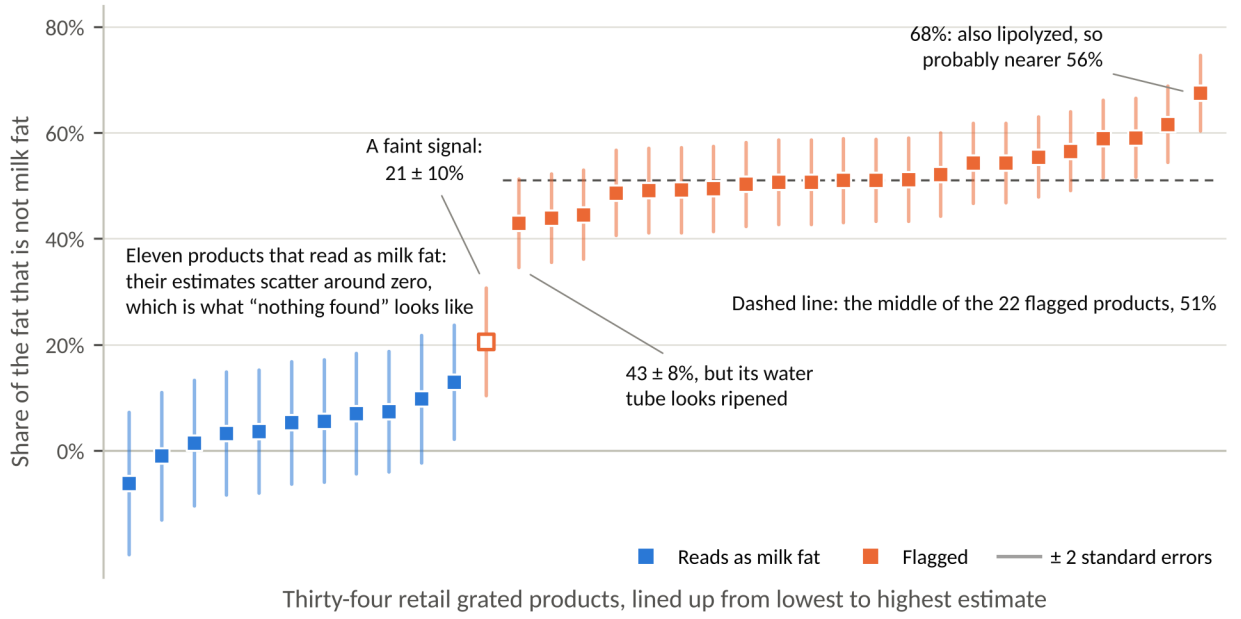

Figure 7. The estimates. Thirty-four retail grated products in order of their estimated non-milk fat, each with its uncertainty (± 2 standard errors). The other six are lipolyzed milk-fat products, for which butyrate cannot be used and no estimate is given.

This is where the second witness comes in. Caproleate is as particular to milk fat as butyrate is, but when a fat is broken down by enzymes it behaves differently: freed butyrate slips away into the water, while freed caproleate, a longer and oilier molecule, stays in the fat extract and keeps giving its signal. So the two markers tell the two stories apart (Figure 8). If butyrate and caproleate have fallen together, the fat has been diluted. If butyrate alone has fallen, the fat has been lipolyzed, and it is still milk fat.

Both stories turned up. For the 22 flagged products, butyrate alone gave a middle estimate of 50% and caproleate alone 55%: the witnesses agree. Six other grated products had low butyrate, 4.9 to 8.0 chains per hundred, but normal caproleate, normal linoleate and normal chain length, along with a large share of fat-breakdown products (free fatty acids and what is left behind when they are clipped off), 6 to 26% of their chains against half a percent in the reference cheeses. In the three most extreme cases, butyrate by itself would have said "43 to 46% not milk fat"; caproleate said 4 to 9%, which is no different from zero. And the missing butyrate was found where the chemistry said it would be, in the water tube of the same products, up to three times stronger than in ordinary cheese. These are lipolyzed cheeses, the kind one expects of a Romano made with lipase or of a product flavored with enzyme-modified cheese[23,27]. Lipolysis is a matter of flavor, not of identity.

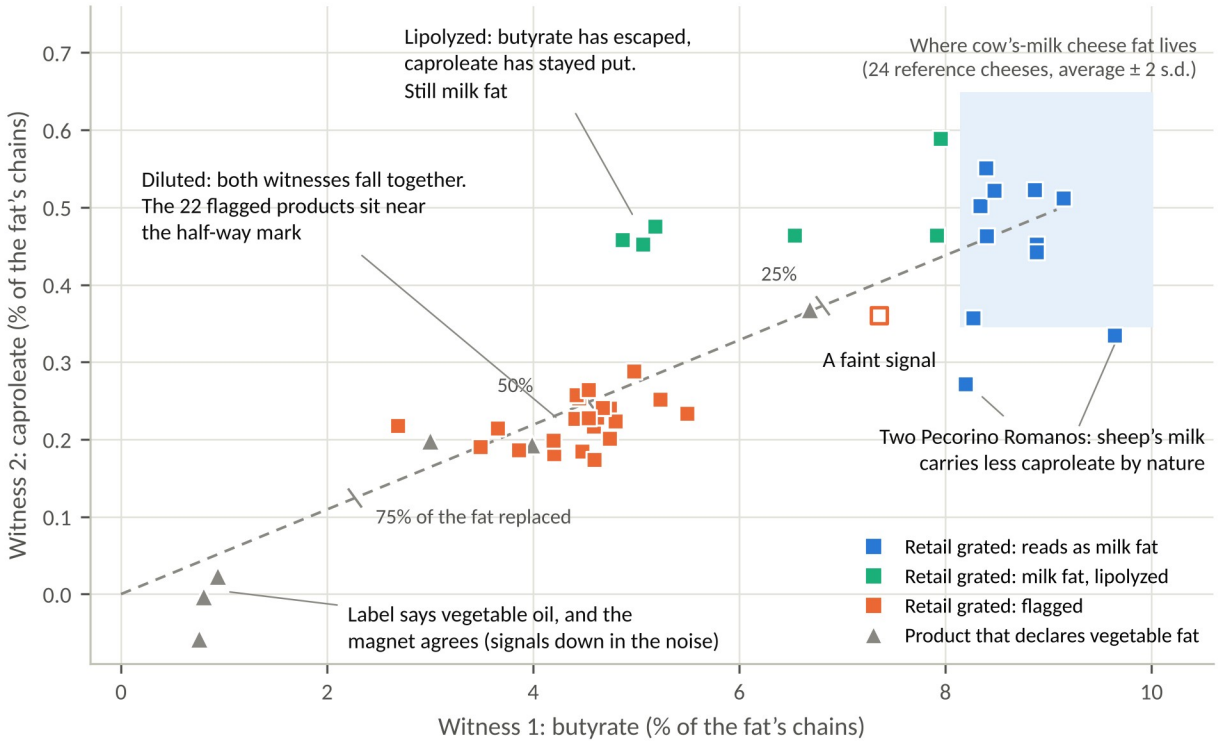

Figure 8. Two witnesses. The 40 retail grated products and the six products that declare vegetable fat, by butyrate and caproleate. Diluted fats fall along the dashed line toward the origin; lipolyzed milk fats move left without moving down. One product, drawn as an open square, gave only a faint indication.

What is the other half of the fat in the flagged products? Subtracting the milk-fat part leaves a fat with about 7 linoleate chains per hundred, no measurable omega-3 chains, 39% monounsaturated and 53% saturated chains, and an average length of 16.4 carbons. That is consistent with a palm-type fat, although it is not a match for the one bottle of whole palm oil in our reference set, which was less saturated. It is very close to the fat of the three grated "cheese products" that declare vegetable oil on their labels. We can say what the fat resembles. We cannot name the oil.

The declared products make a useful sanity check, because their labels admit what the magnet is being asked to find. The grated blend that lists palm oil came out at 26 ± 10%. The imitation topping came out at 57 ± 7% and the prepared cheese loaf at 65 ± 7%, the loaf with a much more unsaturated, seed-oil type of fat. The three grated cheese products and the three plant-based products had their butyrate down at the level where signal cannot be told from noise, so all that can be said is "at least 86%". The method cannot tell 86% from 100%.

The water tube: a second opinion

Had the story ended with the fat, it would be a story about oil. The water tube makes it a story about cheese (Figure 9). In 21 of the 22 flagged products the water extract was not that of a ripened hard cheese. The free amino-acid index had a middle value of 9.7 (range 4.4 to 16.4), against 35 (range 28 to 45) for the 16 products with milk fat. Citrate was present in all 21, with a middle value of 50, where a ripened cheese has none. So were free sugars, though oddly little lactose: mostly galactose and glucose-type sugars, with a trace of a starch-like signal. In 20 of the 21, fat had been carried into the water, at a

level (about 1,700) like that of the processed slices. And in the six that were tested for calcium, the water held about a quarter as much calcium as that of the milk-fat products (73 to 98 against 217 to 367 mg per 100 g) and twice as much phosphorus, which is the pattern that phosphate emulsifying salts would leave.

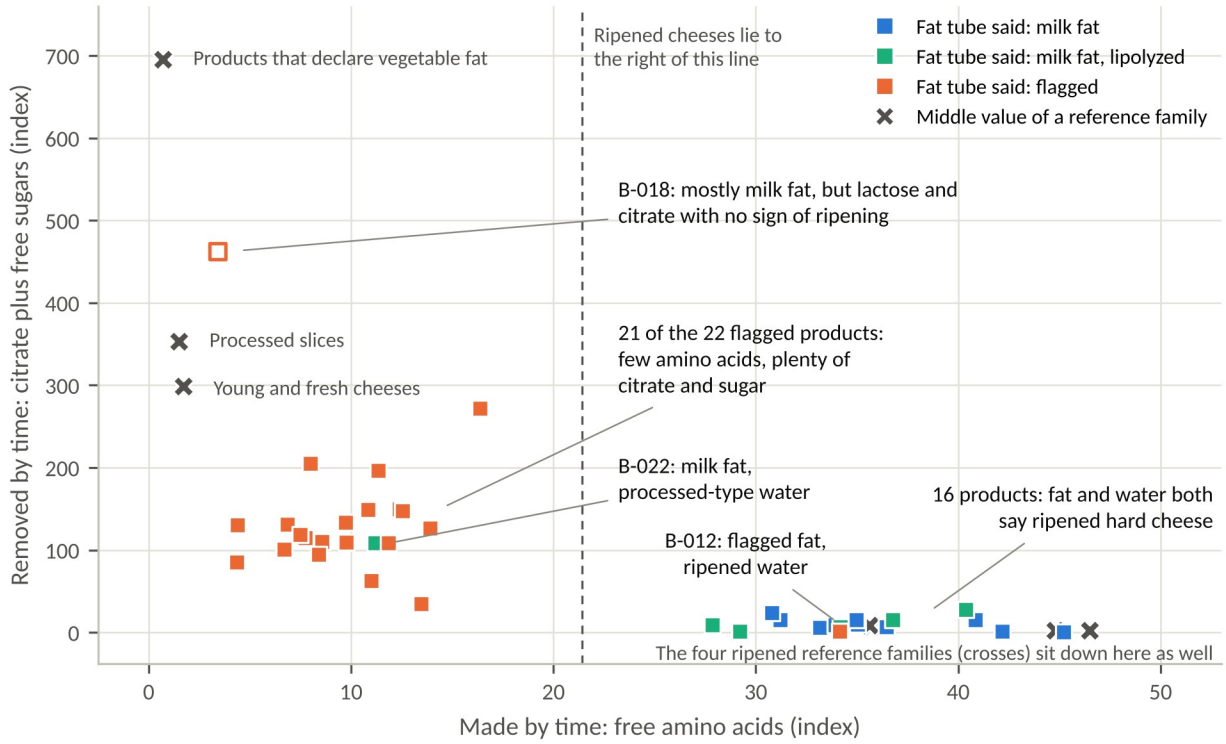

Figure 9. Two tubes, one story. Each retail grated product is placed by what its water tube measured and colored by what its fat tube had already said. Ripened cheese sits at the lower right: plenty of free amino acids, no citrate or sugar left.

One wrinkle belongs here. The amino-acid index is a share of the spectrum, so it falls whenever anything else, such as sugar, citrate or dispersed fat, adds to the total. Counted in other ways, the free amino acids of the flagged group are still lower, by a factor of somewhere between two and four. That is enough to say that the extract as a whole is not that of a ripened cheese. It is not enough to say how old the cheese portion of the product is, and the white paper draws no conclusion about that.

Put the two tubes together and the 40 products fall into the categories of Table 3. One composition that would account for the largest group is a blend of real grated hard cheese with a cheese analogue made from vegetable fat, a dairy or casein base and emulsifying salts. On that reading the milk fat and the amino acids come from the cheese portion, and the replacing fat, the citrate, the sugars and the emulsified fat come from the analogue. It is offered as plausible, not as established: a single manufactured product formulated with some cheese in it would fit the data as well.

Table 3. The scorecard: the 40 retail grated products by what the two tubes showed.

Category	Products	The fat tube	The water tube	Reading
A	11	Milk fat	Ripened: amino acids high, no citrate or sugar	Consistent with grated hard cheese made from milk fat
B	5	Milk fat, lipolyzed	Ripened	The same, with a sharper, lipase-driven character
C	21	43 to 68% not milk fat	Processed type: few amino acids; citrate, sugars and emulsified fat	Not the profile of a grated hard cheese in either tube
D	1	43 ± 8% not milk fat	Ripened in every respect	Unresolved: see text
E	1	Milk fat, slightly lipolyzed	Processed type	Unresolved: see text
F	1	Mostly milk fat; a faint signal of 21 ± 10%	Lactose and citrate, almost no amino acids	Unlike anything else in the set

Three products refused to be sorted. Two of them are mirror images: one has flagged fat with a perfectly ripened water profile, the other has milk fat with a processed-type water profile, and their sample codes differ by a single digit. Either they are two unusual products, or two tubes changed places on the bench. The spectra cannot settle it, and neither product should be cited for anything until both have been extracted again from retained material. The third is stranger: mostly milk fat, but a water extract full of lactose and citrate with almost no free amino acids, which suggests a large contribution from unfermented dairy solids or a very young cheese.

Finally, 43 further fat spectra that had been kept aside were scored with the same rules, unchanged. Nineteen were flagged, at 44 to 62%. That sounds like independent confirmation and is not: the 19 spectra come from just five products, and 17 of them are repeat purchases of three. What they do show is taken up in the next section.

What is not being claimed

“Flagged” is a laboratory word, not a legal one. It means that several markers in a spectrum departed together from the reference cheeses. The data do not identify the oil, the supplier, the recipe or the manufacturing route. They do not say how much cheese is in any container, because the fat content of the products was not measured and the estimate is a share of the fat, not of the product. They do not say how long the cheese in a blend was aged.

They also say nothing about cellulose, the ingredient that made the headlines, because cellulose dissolves in neither solvent. A product in category A could still contain more anticaking agent than it needs. And the whole study rests on one laboratory, one extraction per product and a method that has not yet been checked against an official reference method. For these reasons individual products are described by type only, here and in the white paper.

8. From Detective Work to Day Job: Quality Control

Everything so far has been a detective story, and detective stories make a method look more exotic than it is. Turn the same measurement around and it becomes something a cheese plant could use every working day. A company that grates, blends or ripens cheese has the same questions we had, only about its own goods. Is this delivery what the supplier said it was? Is today's lot the same as last month's? Is the cheese in room four ready?

A quality-control system built on the two tubes would have four parts. The first is a **library of normal**: spectra of the plant's own good production, enough of them, over enough seasons, to know the usual value and the usual spread of every marker. The second is a score for each new sample:

$$z = (\text{value measured} - \text{usual value}) \div \text{usual spread} \quad (5)$$

A score near zero is business as usual; beyond about 3 in either direction, somebody should take a look. In this study the usual butyrate was 9.1 with a spread of 0.47, so a product with 4.5 scores (4.5 − 9.1) ÷ 0.47, or nearly −10. That is not a subtle result. The third part is a **chart**: each lot's score plotted in order of production, so that a slow drift shows up before it becomes a problem. The fourth is a rule that two markers of different chemistry must agree before an alarm is believed. Section 7 showed why: butyrate alone would have raised a false alarm on six lipolyzed cheeses whose fat was milk fat all along.

Table 4 lists the questions such a system could put to each tube. They are possibilities that the markers in this study make plausible. None has yet been validated as a control method, and the validation that would be needed is described in Section 12.

Table 4. Questions a cheese plant could put to the two tubes.

The question	Tube	What to measure	What a departure suggests
Is the fat all milk fat?	Fat	Butyrate and caproleate, with linoleate and chain length	Both milk-fat markers down and vegetable-oil markers up: another fat is present
Has the fat been broken down?	Both	Free fatty acids in the fat tube; free butyrate in the water tube	Lipolysis: intended in Romano and blue cheese, a rancidity defect elsewhere
Was this cheese ripened?	Water	Free amino acids; leftover sugar and citrate	Few amino acids with sugar or citrate: a young or unripened base
Has it been through a processing kettle?	Water	Citrate, emulsified fat, soluble calcium and phosphorus	The work of emulsifying salts
Is the fermentation on track?	Water	Lactose falling and lactate rising; propionate and acetate in Swiss types	A slow starter, or a second fermentation that has stalled or run away
Is today's lot like the last one?	Both	The whole fingerprint against the library of normal	Drift in the milk, the culture, the process or a supplier
Does the label match the contents?	Both	Declared ingredients against what is seen: sorbate, sugars, starch-like signals, vegetable fat	Something undeclared, or something missing

The study contains one small demonstration of the chart idea, though not from the products one would have chosen for it. Three grated Parmesan products among the further fat spectra mentioned in Section 7 had been bought over and over, four, six and seven separate purchases, and every purchase was measured (Figure 10). Their butyrate barely moved: 4.15 ± 0.21, 4.07 ± 0.47 and 4.21 ± 0.23 chains per hundred, which reads as 55, 56 and 55% non-milk fat. Whatever these products are, they are made to a consistent recipe. (Each lot was measured once, so the small scatter includes the wobble of the measurement as well as any real difference between lots.) A maker of traditional grated cheese would draw the same chart and hope to see the dots sitting just as tightly, inside the blue band.

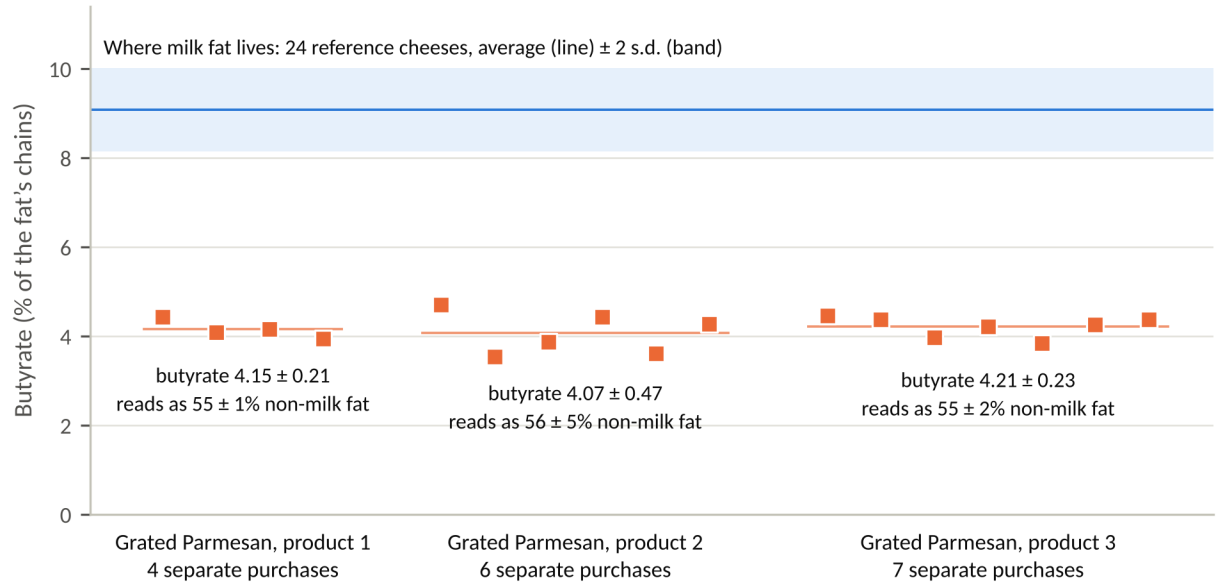

Figure 10. Consistency from lot to lot. Butyrate in separate retail purchases of three flagged grated Parmesan products, against the range of the milk-fat reference cheeses. Values below each group are the average and the standard deviation between purchases.

The white paper also asked whether clever statistics could do the sorting unaided. Seven kinds of machine-learning model were trained on the spectra and tested with the proper precautions. They told milk fat from non-milk fat about 90% of the time and a ripened base from a processed one about 82% of the time, which is good. They named the cheese style, out of nine families, only about half the time, which is not: three to seven examples of a family are too few to teach a computer the difference between a Gruyère and a Gouda. The plain ratios did at least as well on the questions that mattered, and they have one decisive advantage in a quality system or a kitchen argument. Each of them can be explained by pointing at a peak.

How small a substitution would the alarm catch? When real spectra were mixed in the computer, it rang for half of the blends at 20% palm oil and for every one of them at 30%. This is a screen for wholesale substitution, in other words, not for a 5% trim, and those figures come from simulations, not from weighed mixtures.

9. Watching a Cheese Grow Up

No single wheel was followed through its life in this study. What we have instead is a class photograph: cheeses of many ages, from fresh mozzarella to a Gouda of 26 months. Reading across them is like judging how children grow by visiting a school, imperfect but instructive. Here is the life of a cheese as the water tube would record it.

The first days belong to sugar. Starter bacteria turn lactose into lactic acid; in the tube the sugar peaks shrink and the lactate peak grows. Lactose is a double sugar, half glucose and half galactose, and if both halves are fermented one molecule of it gives four of lactic acid:

$$\mathbf{1\ lactose \rightarrow 4\ lactic\ acid} \tag{6}$$

Not every starter finishes the job. The bacterium used for mozzarella eats the glucose half and leaves the galactose behind, which is why the low-moisture mozzarellas in the study were full of free galactose, and also why pizza browns: the leftover sugar scorches in the oven[28,29]. And one fresh mozzarella had almost no lactate at all, with a good deal of acetate in its place, the signature of a curd soured directly with vinegar instead of by bacteria. The tube can tell how the acid got there.

The first weeks belong to citrate. Milk carries citrate of its own, and certain starter bacteria, those of Gouda in particular, ferment it into carbon dioxide and diacetyl, the molecule that smells of butter[30]. In the spectrum the four citrate lines fade away. The young cheeses in the study still had theirs (an index of about 42), the Gouda family had almost none (about 5), and the Grana, sheep's-milk and alpine cheeses had none at all.

The months belong to protein. Enzymes from the rennet, the milk and the spent starter cells take the casein apart, and free amino acids pile up[31]. The index climbs from 2 in a fresh mozzarella to 12 in a fresh Asiago, 29 in a six-month Manchego and 40 to 48 in cheeses of ten to twelve months (Figure 11). In a mature Grana cheese the free amino acids come to roughly a fifth to a quarter of all the nitrogen in the cheese[32].

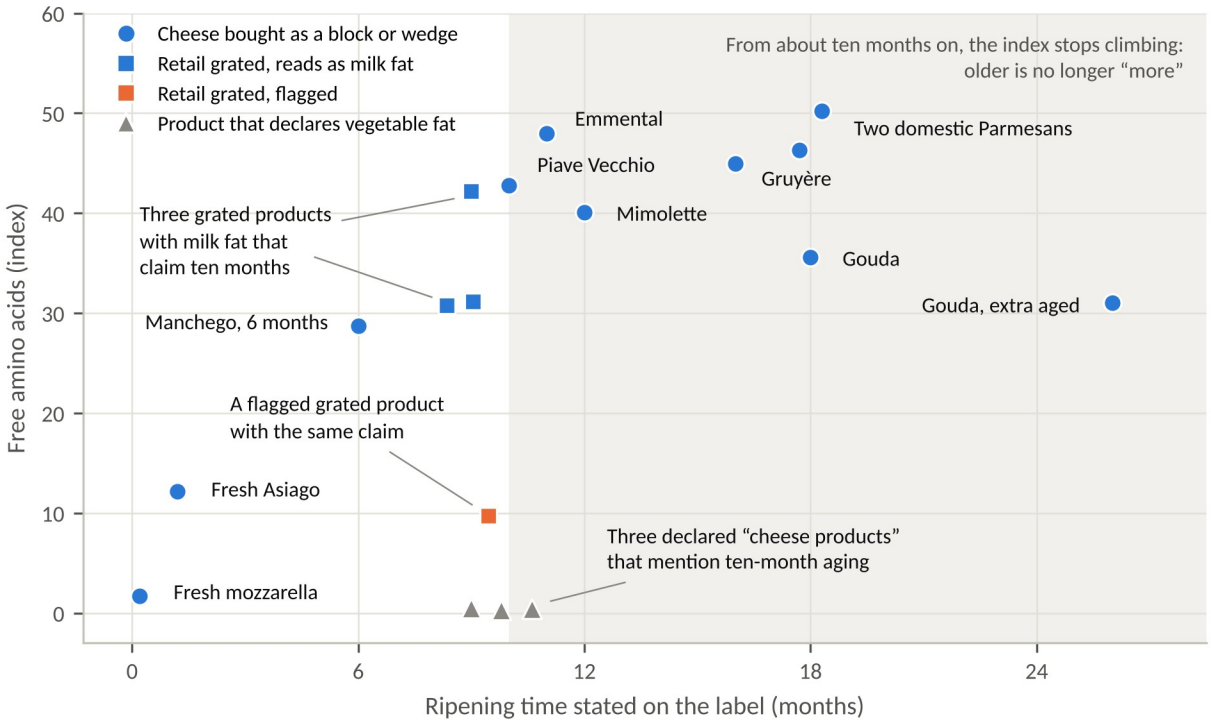

Figure 11. The ripening curve, as far as this study can draw it. Free amino acids against the age stated on the label, for the cheeses and products that carry one. Emmental's value is somewhat overstated, because one of its propionate signals falls in the same window of the spectrum.

Then the curve flattens. Two domestic Parmesans of 18 months scored 46 and 50, a 16-month Gruyère 45, and Goudas of 18 and 26 months only 36 and 31. Older is no longer more. Part of the reason is arithmetic: the index is a share of the spectrum, and in an old cheese the amino acids already are most of the spectrum. Part is chemistry: amino acids are consumed as well as released (their breakdown products are a large part of cheese aroma[33]), and tyrosine drops out as crystals. And part is simply that a Gouda is not a Parmesan. Cheese types differ from one another by more than a mature cheese changes in a year.

So the method as it stands can say, without ambiguity, whether a natural cheese is young or has been ripened for ten months or more. It cannot tell 12 months from 18 or 24. Others have shown that this is possible, by staying within one cheese type, using wheels of documented age, measuring true concentrations and letting statistics read the whole spectrum; ripening stages of Parmigiano Reggiano and Grana Padano have been resolved in that way[34–37]. There is even a candidate for a chemical clock: pyroglutamate, a molecule that forms slowly from glutamate and builds up steadily in Grana cheeses[38]. At 300 MHz its signal hides behind a neighbor, which is a reason to borrow a bigger magnet and not a reason to give up.

Some cheeses have a second act. Emmental wheels are moved to a warm room, where a different bacterium takes over, eats the lactic acid and turns it into propionic acid, acetic acid and carbon dioxide[39,40]:

3 lactate → 2 propionate + 1 acetate + 1 carbon dioxide (7)

The gas blows the holes. The propionate gives Swiss-type cheese its sweet, nutty note. And the whole transaction is on record in the water tube (Figure 12): lactate in the Emmental was down to an index of 81, against 200 to 740 in its alpine cousins, with propionate and acetate standing in its place. Real cheese is messier than the textbook (we found less propionate, relative to acetate, than the two-to-one of the equation), but the signature is unmistakable, and a cheesemaker could follow the second fermentation with a sample smaller than a pea.

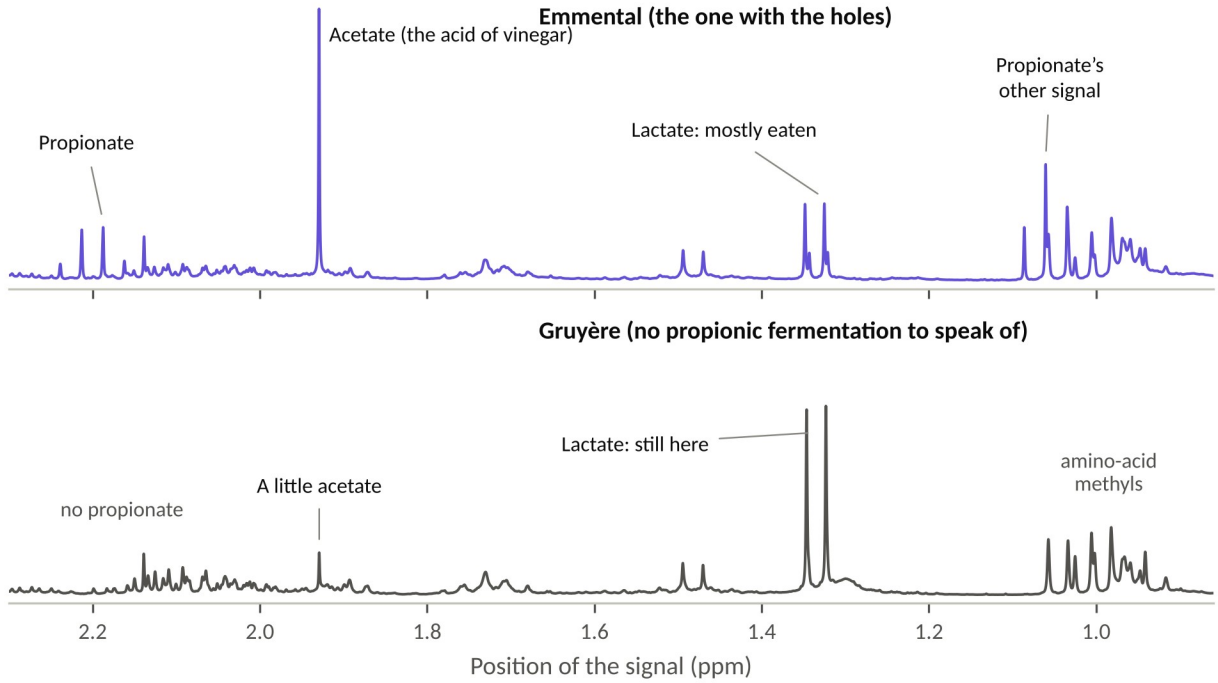

Figure 12. The holes leave a fingerprint. Part of the water spectrum of Emmental (top) and Gruyère (bottom) on one vertical scale. In Emmental the lactate has been converted into propionate and acetate; in Gruyère, which has little or no propionic fermentation, the lactate is still there.

And all the while the fat slowly gives up fatty acids. Free butyrate in the water tube was highest in the lipolyzed grated products and in Parmigiano Reggiano, moderate in the other ripened cheeses and nearly absent from processed cheese. It is the process the fat tube sees from the other side.

None of this was measured here as a time course, and a plant that wanted to use it would begin by sampling its own vats and wheels at intervals. The idea is not far-fetched. Research groups have already explored NMR, alongside near-infrared spectroscopy, as a monitor for semi-hard cheeses in production, and have proposed sets of marker molecules for predicting ripeness and quality[41,42].

One last use of the ripening curve leads back to the shakers. Three retail grated products with milk fat stated that their cheese was aged ten months, and their indices, 31 to 42, are what a ten-month cheese should give. A flagged product with the same claim gave 10, and three declared cheese products that mention ten-month aging gave less than 1. That does not prove that the cheese inside them was young, because a fully aged cheese diluted with material that contains no amino acids would give a low reading too. It shows only that the product as a whole is not a ripened cheese, which, for the declared products, is just what their labels say.

10. Chemistry You Can Taste

Flavor is two senses doing one job. The tongue handles taste proper: salty, sour, sweet, bitter and the savory taste called umami, along with a sense of fullness that food scientists call kokumi. The nose handles aroma, which is hundreds of volatile molecules at vanishingly small concentrations. NMR is a good tongue and a poor nose. It sees the molecules that are present at a tenth of a percent and more, which are the taste molecules, and it misses the aroma molecules, which work at parts per billion and need other instruments.

The taste side has been mapped for cheese in remarkable detail. One research group took Parmesan apart molecule by molecule, measured 65 candidate taste compounds and then rebuilt the taste from pure chemicals. Thirty-one compounds turned out to matter, among them amino acids, organic acids, fatty acids and minerals, and a tasting panel judged the reconstruction a match for the cheese[43]. In Cheddar and Swiss cheese, glutamate was shown to be the main source of umami, with help in the Swiss from propionate and succinate[44]. Most of the molecules on those lists are molecules that our two tubes already count (Table 5).

Table 5. From peak to palate: taste-active components of cheese, where the measurement sees them, and what they contribute.

Component	Where the magnet sees it	What it contributes
Lactic acid	Water tube: the tallest peak	Clean sourness; the tang of a young cheese
Glutamate and the other free amino acids	Water tube: the forest of peaks	Umami and brothy depth; some are sweet, some bitter
Free butyric acid and other short fatty acids	Water tube, and as missing butyrate in the fat tube	Sharp and piquant in a Romano; rancid when overdone
Propionate and acetate	Water tube, in Swiss types	Sweet and nutty; a touch of vinegar
Citrate	Water tube: four lines	Tartness; a sign of youth, or of emulsifying salts
Lactose and galactose	Water tube: the sugar region	Faint sweetness; browning in the oven
Calcium and phosphate	Water tube with EDTA for calcium; a separate phosphorus measurement	Felt more than tasted: firmness, melt and stretch
Salt	Invisible in a hydrogen spectrum; a separate sodium measurement can count it	Saltiness
Milk fat	Fat tube	Richness and mouthfeel

To learn which of these molecules drives a particular impression in a particular cheese, the spectra have to be introduced to a tasting panel. A sensory panel is a group of trained tasters who score each sample for defined attributes, such as sharpness, saltiness, bitterness, nuttiness and crumbliness, on numerical scales. Give the same set of cheeses to the panel and to the magnet, and a statistical method called regression will look for the combination of peaks that best predicts each score:

$$\text{predicted score for “sharp”} \approx a \times (\text{free butyrate}) + b \times (\text{lactate}) + c \times (\text{free amino acids}) + \ldots \quad (8)$$

The weights a, b and c are learned from the data, and the workhorse for spectra is a technique called partial least squares[45]. A large weight says that a molecule travels with the sensation. It does not prove that the molecule causes it. The proof is the kind of experiment described above for Parmesan: add the molecule to a bland base, or leave it out of a reconstruction, and ask the panel whether they notice.

This has been done with cheese and NMR. In a study of reduced-salt Gouda, a trained panel and high-field NMR were applied to the same cheeses, and the chemical fingerprints, read with multivariate statistics, tracked the ripening time and the effect of added cultures[46]. Applied to the present subject, the same design could answer practical questions. Which grated products taste flat, and why? How much free butyrate makes a Romano pleasantly sharp, and how much is too much? When has a wheel reached the flavor its maker is after? Such a project needs a few dozen samples that span the range of interest, and it works better with true concentrations than with shares of a spectrum.

We should be plain about what was done here: **no tasting panel was part of this study**, and nothing in the white paper says how any product tastes. The spectra show which taste-active molecules are present and in what proportion. Connecting them to perception is a project of its own, and a good one.

11. Back in the Kitchen

Grated Parmesan has been an object of desire for a very long time. Around 1350, Boccaccio's *Decameron* told of a land called Bengodi with a mountain made entirely of grated Parmesan, on which the inhabitants did nothing but make macaroni and ravioli, cook them in capon broth and toss them down the slope for whoever could catch the most[47]. Nobody in Bengodi had to read the label. For the rest of us there is chemistry, all of it edible, and most of it explains something a cook already knows.

Aged Parmesan is a seasoning as much as a cheese. A year or two of proteolysis has turned a good part of its protein into free amino acids, glutamate among them, so a spoonful stirred into a risotto or shaved over a salad works the way a splash of good stock does. The crunch in a well-aged piece is tyrosine that has crystallized out[9]. Because the protein network has been so thoroughly taken apart, and because the cheese is dry, it grates to a powder and dissolves into a sauce instead of stretching. The rind, simmered in a pot of soup, gives up the same savory molecules.

Pecorino Romano is the sharp one, and the reason is now clear. The lamb rennet paste used to make it brings a lipase, the lipase frees short fatty acids, and free butyric acid in small doses is piquant[23]. The cheese is also salted heavily. That bite is what stands up to black pepper in cacio e pepe and to cured pork in carbonara, and it is why a recipe written for Pecorino tastes different with Parmesan.

Mozzarella is the opposite case, a cheese valued for what has not happened to it yet. Its protein is still a continuous network held together with calcium, which is why it stretches[48]. It has almost no free amino acids, which is why it is mild. And its leftover galactose is why it blisters and browns on a pizza[29].

Processed cheese melts into a smooth sheet instead of an oily puddle, and the emulsifying salts are the reason. By pulling calcium off the protein they turn the protein into an emulsifier that holds fat and water together through heating[24]. It is the same chemistry that showed up in the water tube as citrate, dispersed fat and missing calcium, and it is the secret of every cheeseburger slice.

Emmental and Gruyère owe their sweet, nutty character to the second act described in Section 9, which, with their smooth melting, makes them the fondue cheeses. **Blue cheese** is the most thoroughly dismantled of all: its mold breaks down fat and protein alike and eats the lactic acid for good measure, which leaves the strongest flavor in the shop[22].

And the shaker? A powder built on vegetable fat and a processed-type base will still sprinkle, and it will still be salty. By the chemistry it brings a fraction of the free amino acids of a grated aged cheese (between a quarter and a half, depending on how one counts), and, on these estimates, roughly half of its fat is not butterfat. Whether that matters on a Tuesday-night plate of spaghetti is a question for the cook and not for the spectrometer. The point of a standard of identity is only that the name on the label and the contents of the container should agree.

For shoppers, the practical advice is older than NMR. Buy the wedge when you can, with the name stamped in the rind, and grate it yourself. If you buy it grated, read the small print: “Parmesan cheese” and “Parmesan cheese product” are different things, and so are “Romano” and “Pecorino Romano”. A short ingredient list (milk, salt, cultures and enzymes, plus an anticaking agent and a mold inhibitor in a grated cheese) is a good sign. Vegetable oil, starch and emulsifying salts say that you are holding something else, which may be exactly what you want, as long as you know.

12. What the Magnet Cannot See, and What Comes Next

Every method has a blind side, and this one has several. It cannot see **cellulose** or any other insoluble filler, so it has nothing to say about the ingredient that started the public conversation. It measures the make-up of the fat and not the amount of fat, so its estimates are shares of the fat and cannot be turned into grams of vegetable oil per serving. Below a certain level its milk-fat markers disappear into the noise, so it cannot tell a product with a little milk fat from a product with none. Its alarm has been tuned on the kind of fat that was actually found; a fat of a different character (coconut-type fats are the obvious example) would move the markers in a different way, and that case has not been tested on real blends. And the water-tube indices are shares of a spectrum, which are fine for sorting ripened from unripened and treacherous for anything finer.

Then there are the limits of this particular study, as distinct from the method. One laboratory. One extraction of each product. A reference population of 24 retail cheeses that are presumed, not certified, to be authentic. No side-by-side comparison with the official gas-chromatographic method for the purity of milk fat[49]. And a handful of sample records that disagree with one another. The main pattern is supported from several directions: by chemically different markers, by both tubes, and by further lots of some of the same products. It still rests on everything listed in this paragraph, and that is the difference between a screen and a verdict[50].

The white paper ends with a to-do list, and it is the right one. Make up blends of real grated Parmesan with known, weighed amounts of palm oil and of a commercial cheese analogue, and see whether the method reports what was put in. Analyze a set of cheeses of documented origin that played no part in setting the limits, to learn how often the alarm rings when it should not. Extract the same lot several times, to learn how repeatable the whole procedure is. Add a weighed reference compound to every tube, so that shares become concentrations. Measure the fat content, so that a share of the fat becomes a share of the product. Send a subset of the samples for gas chromatography.

A magnet walked into a cheese shop and came out with two findings. The narrow one concerns forty containers: sixteen were what a grated hard cheese should be in both tubes, twenty-two were flagged, and a flag is an invitation to look harder, not a conviction. The broad one will outlast it. A pinch of cheese, two solvents and a few minutes of magnet time are enough to read back much of a cheese's biography: what kind of milk the fat came from and what has happened to it since, whether the sugar was eaten, how far the protein has been taken apart, whether the holes were blown, whether the salts of the processing kettle have been through. That is a great deal of chemistry to get out of a powder, and nearly all of it is delicious.

References

1. Fox, P. F.; Guinee, T. P.; Cogan, T. M.; McSweeney, P. L. H. Fundamentals of Cheese Science; Springer US, 2017. https://doi.org/10.1007/978-1-4899-7681-9
2. Gobbetti, M.; Neviani, E.; Fox, P. The Cheeses of Italy: Science and Technology; Springer International Publishing, 2018. https://doi.org/10.1007/978-3-319-89854-4
3. U.S. Food and Drug Administration. Parmesan and Reggiano Cheese. Code of Federal Regulations, Title 21, Section 133.165. https://www.ecfr.gov/current/title-21/chapter-I/subchapter-B/part-133/subpart-B/section-133.165 (accessed November 9, 2026).
4. Bloomberg News. The Parmesan Cheese You Sprinkle on Your Penne Could Be Wood. Bloomberg, February 16, 2016; republished by Dairy Herd. https://www.dairyherd.com/news/parmesan-cheese-you-sprinkle-your-penne-could-be-wood (accessed November 9, 2026).
5. Edwards, J. C. Paired ^{1}H NMR Screening of Retail Grated Cheese: Lipid and Aqueous Extracts of 84 Cheese Products at 300 MHz, Evaluated by Ratiometric, Chemometric and Machine-Learning Methods against Reference Cheeses of Nine Classes; White Paper, Version 2.2; Process NMR Associates, LLC: Poughkeepsie, NY, November 15, 2026.
6. Tunick, M. H. The Science of Cheese; Oxford University Press: New York, 2014.
7. McSweeney, P. L. H. Biochemistry of cheese ripening. International Journal of Dairy Technology 2004, 57 (2–3), 127–144. https://doi.org/10.1111/j.1471-0307.2004.00147.x
8. McSweeney, P. L. H.; Sousa, M. J. Biochemical pathways for the production of flavour compounds in cheeses during ripening: A review. Le Lait 2000, 80 (3), 293–324. https://doi.org/10.1051/lait:2000127
9. Tansman, G. F.; Kindstedt, P. S.; Hughes, J. M. Crystal fingerprinting: elucidating the crystals of Cheddar, Parmigiano-Reggiano, Gouda, and soft washed-rind cheeses using powder x-ray diffractometry. Dairy Science & Technology 2015, 95 (5), 651–664. https://doi.org/10.1007/s13594-015-0225-6
10. U.S. Food and Drug Administration. Romano Cheese. Code of Federal Regulations, Title 21, Section 133.183. https://www.ecfr.gov/current/title-21/chapter-I/subchapter-B/part-133/subpart-B/section-133.183 (accessed November 9, 2026).
11. U.S. Food and Drug Administration. Grated Cheeses. Code of Federal Regulations, Title 21, Section 133.146. https://www.ecfr.gov/current/title-21/chapter-I/subchapter-B/part-133/subpart-B/section-133.146 (accessed November 9, 2026).
12. Bachmann, H.-P. Cheese analogues: a review. International Dairy Journal 2001, 11 (4–7), 505–515. https://doi.org/10.1016/s0958-6946(01)00073-5
13. Guinee, T. P. Pasteurized Processed and Imitation Cheese Products. In Cheese; Elsevier, 2017; pp 1133–1184. https://doi.org/10.1016/b978-0-12-417012-4.00046-6
14. Grossmann, L.; McClements, D. J. The science of plant-based foods: Approaches to create nutritious and sustainable plant-based cheese analogs. Trends in Food Science & Technology 2021, 118, 207–229. https://doi.org/10.1016/j.tifs.2021.10.004
15. Tomé, D. Yeast Extracts: Nutritional and Flavoring Food Ingredients. ACS Food Science & Technology 2021, 1 (4), 487–494. https://doi.org/10.1021/acsfoodscitech.0c00131

16. 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. Journal of Microbiology and Biotechnology 2023, 33 (2), 151–166. https://doi.org/10.4014/jmb.2207.07057
17. Jensen, R. G. The Composition of Bovine Milk Lipids: January 1995 to December 2000. Journal of Dairy Science 2002, 85 (2), 295–350. https://doi.org/10.3168/jds.s0022-0302(02)74079-4
18. Lindmark Månsson, H. Fatty acids in bovine milk fat. Food & Nutrition Research 2008, 52 (1), 1821. https://doi.org/10.3402/fnr.v52i0.1821
19. Tociu, M.; Todasca, M.-C.; Bratu, A.; Mihalache, M.; Manolache, F. Fast approach for fatty acid profiling of dairy products fats using ^{1}H-NMR spectroscopy. International Dairy Journal 2018, 83, 52–57. https://doi.org/10.1016/j.idairyj.2018.03.005
20. Hanganu, A.; Chira, N.-A. When detection of dairy food fraud fails: An alternative approach through proton nuclear magnetic resonance spectroscopy. Journal of Dairy Science 2021, 104 (8), 8454–8466. https://doi.org/10.3168/jds.2020-19883
21. Collomb, M.; Schmid, A.; Sieber, R.; Wechsler, D.; Ryhänen, E.-L. Conjugated linoleic acids in milk fat: Variation and physiological effects. International Dairy Journal 2006, 16 (11), 1347–1361. https://doi.org/10.1016/j.idairyj.2006.06.021
22. Collins, Y. F.; McSweeney, P. L. H.; Wilkinson, M. G. Lipolysis and free fatty acid catabolism in cheese: a review of current knowledge. International Dairy Journal 2003, 13 (11), 841–866. https://doi.org/10.1016/s0958-6946(03)00109-2
23. Addis, M.; Piredda, G.; Pirisi, A. The use of lamb rennet paste in traditional sheep milk cheese production. Small Ruminant Research 2008, 79 (1), 2–10. https://doi.org/10.1016/j.smallrumres.2008.07.002
24. Kapoor, R.; Metzger, L. E. Process Cheese: Scientific and Technological Aspects—A Review. Comprehensive Reviews in Food Science and Food Safety 2008, 7 (2), 194–214. https://doi.org/10.1111/j.1541-4337.2008.00040.x
25. Lucey, J. A.; Fox, P. F. Importance of Calcium and Phosphate in Cheese Manufacture: A Review. Journal of Dairy Science 1993, 76 (6), 1714–1724. https://doi.org/10.3168/jds.s0022-0302(93)77504-9
26. Mizuno, R.; Lucey, J. A. Effects of Emulsifying Salts on the Turbidity and Calcium-Phosphate–Protein Interactions in Casein Micelles. Journal of Dairy Science 2005, 88 (9), 3070–3078. https://doi.org/10.3168/jds.s0022-0302(05)72988-x
27. Kilcawley, K. N.; Wilkinson, M. G.; Fox, P. F. Enzyme-modified cheese. International Dairy Journal 1998, 8 (1), 1–10. https://doi.org/10.1016/s0958-6946(98)00010-7
28. Hutkins, R. W.; Morris, H. A. Carbohydrate Metabolism by Streptococcus thermophilus: A Review. Journal of Food Protection 1987, 50 (10), 876–884. https://doi.org/10.4315/0362-028x-50.10.876
29. Mukherjee, K. K.; Hutkins, R. W. Isolation of Galactose-Fermenting Thermophilic Cultures and Their Use in the Manufacture of Low Browning Mozzarella Cheese. Journal of Dairy Science 1994, 77 (10), 2839–2849. https://doi.org/10.3168/jds.s0022-0302(94)77223-4
30. Hugenholtz, J. Citrate metabolism in lactic acid bacteria. FEMS Microbiology Reviews 1993, 12 (1–3), 165–178. https://doi.org/10.1111/j.1574-6976.1993.tb00017.x
31. Sousa, M. J.; Ardö, Y.; McSweeney, P. L. H. Advances in the study of proteolysis during cheese ripening. International Dairy Journal 2001, 11 (4–7), 327–345. https://doi.org/10.1016/s0958-6946(01)00062-0
32. Masotti, F.; Hogenboom, J. A.; Rosi, V.; De Noni, I.; Pellegrino, L. Proteolysis indices related to cheese ripening and typicalness in PDO Grana Padano cheese. International Dairy Journal 2010, 20 (5), 352–359. https://doi.org/10.1016/j.idairyj.2009.11.020
33. Ardö, Y. Flavour formation by amino acid catabolism. Biotechnology Advances 2006, 24 (2), 238–242. https://doi.org/10.1016/j.biotechadv.2005.11.005
34. Consonni, R.; Cagliani, L. R. Ripening and geographical characterization of Parmigiano Reggiano cheese by ^{1}H NMR spectroscopy. Talanta 2008, 76 (1), 200–205. https://doi.org/10.1016/j.talanta.2008.02.022
35. Shintu, L.; Caldarelli, S. High-Resolution MAS NMR and Chemometrics: Characterization of the Ripening of Parmigiano Reggiano Cheese. Journal of Agricultural and Food Chemistry 2005, 53 (10), 4026–4031. https://doi.org/10.1021/jf048141y

36. de Angelis Curtis, S.; Curini, R.; Delfini, M.; Brosio, E.; D'Ascenzo, F.; Bocca, B. Amino acid profile in the ripening of Grana Padano cheese: a NMR study. Food Chemistry 2000, 71 (4), 495–502. https://doi.org/10.1016/s0308-8146(00)00192-8

37. Maestrello, V.; Solovyev, P.; Stroppa, A.; Bontempo, L.; Franceschi, P. ^{1}H NMR profiling and chemometric analysis for ripening and production characterization of Grana Padano cheese. Food Chemistry 2024, 456, 139986. https://doi.org/10.1016/j.foodchem.2024.139986

38. Mucchetti, G.; Locci, F.; Gatti, M.; Neviani, E.; Addeo, F.; Dossena, A.; Marchelli, R. Pyroglutamic Acid in Cheese: Presence, Origin, and Correlation with Ripening Time of Grana Padano Cheese. Journal of Dairy Science 2000, 83 (4), 659–665. https://doi.org/10.3168/jds.s0022-0302(00)74926-5

39. Fröhlich-Wyder, M.-T.; Bachmann, H.-P.; Casey, M. G. Interaction between propionibacteria and starter / non-starter lactic acid bacteria in Swiss-type cheeses. Le Lait 2002, 82 (1), 1–15. https://doi.org/10.1051/lait:2001001

40. Thierry, A.; Deutsch, S.-M.; Falentin, H.; Dalmasso, M.; Cousin, F. J.; Jan, G. New insights into physiology and metabolism of Propionibacterium freudenreichii. International Journal of Food Microbiology 2011, 149 (1), 19–27. https://doi.org/10.1016/j.ijfoodmicro.2011.04.026

41. Patel, H.; Aru, V.; Sørensen, K. M.; Engelsen, S. B. Towards on-line cheese monitoring: Exploration of semi-hard cheeses using NIR and ^{1}H NMR spectroscopy. Food Chemistry 2024, 454, 139786. https://doi.org/10.1016/j.foodchem.2024.139786

42. Chen, Y.; MacNaughtan, W.; Jones, P.; Yang, Q.; Williams, H.; Foster, T. Selection of potential molecular markers for cheese ripening and quality prediction by NMR spectroscopy. LWT 2021, 136, 110306. https://doi.org/10.1016/j.lwt.2020.110306

43. Hillmann, H.; Hofmann, T. Quantitation of Key Tastants and Re-engineering the Taste of Parmesan Cheese. Journal of Agricultural and Food Chemistry 2016, 64 (8), 1794–1805. https://doi.org/10.1021/acs.jafc.6b00112

44. Drake, S. L.; Carunchia Whetstine, M. E.; Drake, M. A.; Courtney, P.; Fligner, K.; Jenkins, J.; Pruitt, C. Sources of Umami Taste in Cheddar and Swiss Cheeses. Journal of Food Science 2007, 72 (6), S360–S366. https://doi.org/10.1111/j.1750-3841.2007.00402.x

45. Wold, S.; Sjöström, M.; Eriksson, L. PLS-regression: a basic tool of chemometrics. Chemometrics and Intelligent Laboratory Systems 2001, 58 (2), 109–130. https://doi.org/10.1016/s0169-7439(01)00155-1

46. Ruyssen, T.; Janssens, M.; Van Gasse, B.; Van Laere, D.; Van der Eecken, N.; De Meerleer, M.; Vermeiren, L.; Van Hoorde, K.; Martins, J. C.; Uyttendaele, M.; De Vuyst, L. Characterisation of Gouda cheeses based on sensory, analytical and high-field ^{1}H nuclear magnetic resonance spectroscopy determinations: Effect of adjunct cultures and brine composition on sodium-reduced Gouda cheese. International Dairy Journal 2013, 33 (2), 142–152. https://doi.org/10.1016/j.idairyj.2013.04.009

47. Boccaccio, G. The Decameron, Day 8, Story 3 (ca. 1353); Payne, J., Transl.; Standard Ebooks. https://standardebooks.org/ebooks/giovanni-boccaccio/the-decameron/john-payne/text/day-8-3 (accessed November 12, 2026).

48. Lucey, J. A.; Johnson, M. E.; Horne, D. S. Invited Review: Perspectives on the Basis of the Rheology and Texture Properties of Cheese. Journal of Dairy Science 2003, 86 (9), 2725–2743. https://doi.org/10.3168/jds.s0022-0302(03)73869-7

49. International Organization for Standardization; International Dairy Federation. Milk and Milk Products: Determination of Milk Fat Purity by Gas Chromatographic Analysis of Triglycerides; ISO 17678:2019 | IDF 202:2019; ISO: Geneva, 2019.

50. Riedl, J.; Esslinger, S.; Fauhl-Hassek, C. Review of validation and reporting of non-targeted fingerprinting approaches for food authentication. Analytica Chimica Acta 2015, 885, 17–32. https://doi.org/10.1016/j.aca.2015.06.003

Summary: Five Things to Remember

Two tubes, two questions. A pinch of each of 84 cheese products was extracted once with chloroform and once with heavy water, and each extract was measured by NMR at 300 MHz. The fat extract answers whether the fat is milk fat. The water extract answers whether the product has the chemistry of a cheese that was ripened. Neither question can be answered from the other tube.

Milk fat carries a flag. About one fatty chain in eleven in cow's milk fat is butyrate, which almost no other food fat contains, and its peak can be counted with simple division. A second marker, caproleate, separates fat that has been diluted (both markers fall) from fat that has merely been broken down by ripening enzymes (only butyrate falls).

Time writes in the water. Ripening removes sugar and citrate and releases free amino acids, so a ripened hard cheese has plenty of the last and none of the first two. Processed cheese shows the reverse, with the fingerprints of emulsifying salts added: citrate, emulsified fat and missing calcium. Special fermentations, such as the one that blows the holes in Emmental, leave their own signatures.

Sixteen, twenty-two and three. Of 40 retail grated Parmesan and Romano products, 16 were consistent in both tubes with grated hard cheese made from milk fat. Twenty-two were flagged for a fat estimated at 43 to 68% non-milk fat (middle value 51%, about ± 8 points), consistent with a palm-type fat, and 21 of those had a processed-type water profile. Three products fit neither pattern. These are screening results from one laboratory. They do not identify the oil, the maker, the proportion of cheese or its age, and the method cannot see cellulose.

The everyday uses may matter most. The same measurement could give a cheese plant a library of normal, a score and a chart for every lot, a way to follow fermentation and ripening from vat to wheel, and, in partnership with a tasting panel, a way to learn which molecules make a cheese taste the way it does. Each of those uses needs validation of its own, beginning with weighed blends, replicate extractions and a comparison with reference methods.