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**Section Questions and Answers (Part 4: Edible Ideas)**

# Questions and answers: when words are analysed from a chemical and physical perspective, innovation is easy

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## Abstract

Seven questions sent by a chef about molecular cooking preparations are considered. The scientific and technical analysis of these questions associated with a terminology discussion leads to many technical solutions. This discussion demonstrates that culinary innovation is easier when it is based on molecular and physical gastronomy.

## Keywords

wording, molecular cooking, solutions.

## Introduction

In this article, seven questions sent by email by a pastry chef are discussed:

1. What is "xanthan", and how is it used? Is it dangerous?
2. How can "herbal pearls" be made?
3. How can "tomato and date mousse" be made?
4. How can "lemon powder" be made?
5. How can "espuma" be made?
6. How can "vanilla emulsion" be made?
7. What is a "protein batter"?

These questions are about common "molecular cooking" preparations, *i.e.*, culinary preparations that are obtained through the use of modern tools transferred from scientific and technological laboratories to kitchens.
For all of them, (1) the wording will first be analysed, (2) leading to a good understanding, so that (3) various culinary solutions can be proposed.

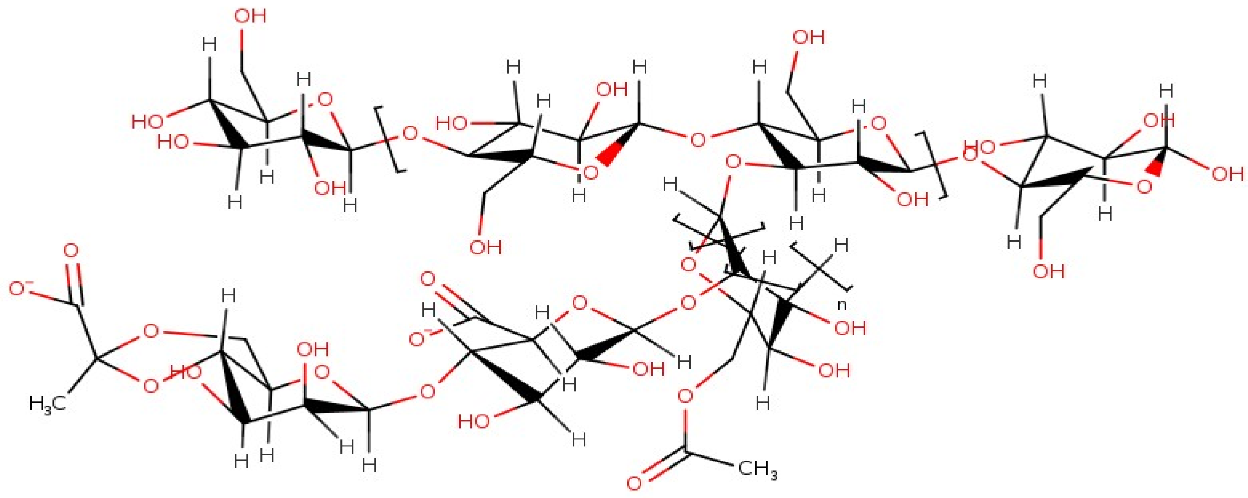

*Figure 1. The chemical structure of xanthan gum molecules.*

**1. What is "xanthan" and how is it used? Is it dangerous?**

Here the question was about "xanthan", and the chef wanted to know what it is, and how it can be used, but it has to be observed that he should have spoken of "xanthan gum", rather than simply "xanthan". Using this more correct terminology, he would have found a large number of Internet pages of different quality, ranging from the very precise to the completely wrong. A reliable source is the *Handbook of Molecular Gastronomy* (Burke *et al.*, 2021).

The word "xanthan" is based on the Greek root *xanthos*, meaning yellow. It comes from the name of the *Xanthomonas* group of bacteria, which sometimes create yellow stains on the leaves of plants. When fermenting corn starch, for example, *Xanthomonas campestris* secrete compounds (see later) that can be recovered by filtration and ethanol precipitation, forming a "gum" called "xanthan gum" (Jecfa, 2016; Edwards-Stuart and Barbar, 2021). This word "gum" is also used for gum arabic, carob bean gum, konjac gum, for example, but there are differences: gum arabic, tragacanth gum, gum karaya and ghatti gum are hardened saps from plants; guar gum, caroub gum and tara gum come from seeds, konjac gum is extracted from a rhizome, and xanthan is a bacterial secretion.

The molecules of xanthan gums are all built in the same way, with repeats of the same molecular motif, but of different lengths, so that their molecular mass is between one and several millions (Faria et al., 2011; Wikipedia, 2023). The molecular motif is a link of D-glucose residues (as in cellulose molecules), with branches made of a succession of three monosaccharides residues: mannose (substituted by acetic acid), D-glucuronic acid and mannose (substituted by pyruvic acid). (Figure 1). The final xanthan gum products are manufactured in the form of a sodium, potassium or calcium salt, and their solutions are neutral.

Xanthan gums, either native or chemically modified, have thickening properties, and gelling properties in association with other polysaccharides, because of the high number of hydroxyl groups (with an oxygen atom linked to an hydrogen atom, -OH) in their molecules. As such groups can establish hydrogen bonds with water molecules, xanthan gums increase the viscosity of the aqueous solution in which they are dissolved. In association with other

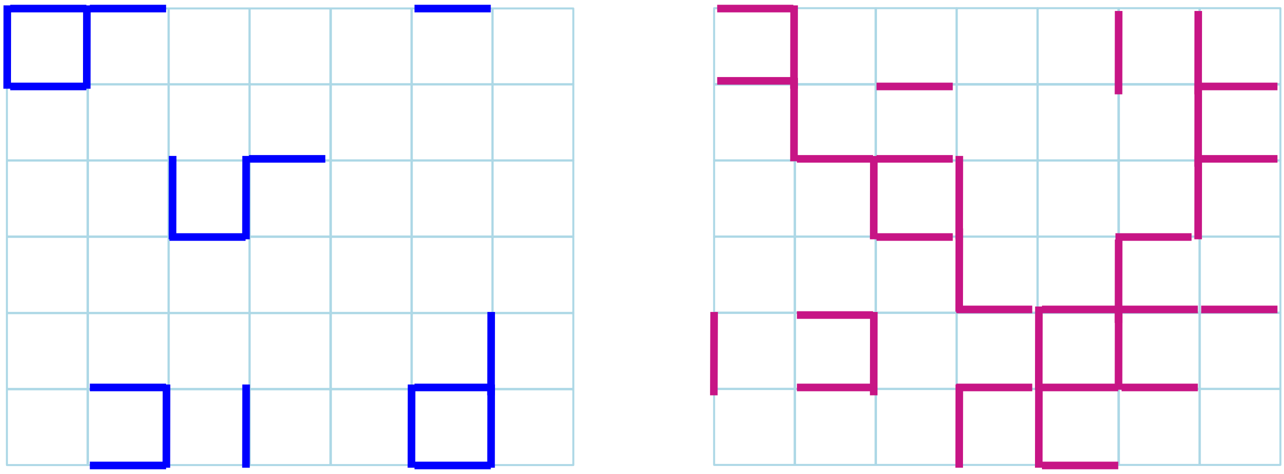

*Figure 2.The theory of percolation explains the difference between a thickened solution (*left*) and a gel (*right*). When monomers that can link are at low concentration (*left*), they can make a local agregate that increases the viscosity of the medium in which they are dispersed. When their concentration is higher than the so-called "percolation threshold", a continuous network can be established, making a gel (*right*).*

polysaccharides (*e.g.* as galatomannans) or mixture of polysaccharides (*e.g.* starch), they can make gels.

Xanthan gums are allowed to be used as food additives (European code E415) for their thickening and gelling properties (EFSA Panel on Food Additives and Flavourings, 2023). The acceptable daily intake (ADI) is "not specified", which means that it can used *quantum satis* without risk for the human health.

After receiving this information, the chef to which the information given here was sent asked why the same product can be used in two different ways, and indeed there is sometimes confusion between thickeners and gelling agents. Products in these two categories are often polymers, *i.e.*, compounds whose molecules are repetitions of a few basic units, called "monomers". For example, cellulose is a polymer of D-glucose residues. Another example is the material known as gelatine, which is made up of many different "polypeptides" (compounds whose molecules are strings of amino acid residues) of the same kind.

The example of gelatine is useful to illustrate the difference between a thickened solution and a gel because it is familiar in classical cooking. When gelatine (powder or sheet) is heated in an aqueous solution (in the culinary context, it can be meat broth, tea, wine, coffee, fruit juice, fish stock, etc.), its molecules disperse among water molecules in the solution; then, on cooling, they slow down and join together at their ends, forming a network whose junction points are small segments of triple helices. When the gelatine concentration is enough (about > 5%, depending on gelatine quality), the network can be continuous, extending throughout the solution. The water molecules are “trapped” in the gel, *i.e.,* unable to flow because of weak chemical bonds with the network. This is a "gel", *i.e.,* a soft solid that does not flow (unless the stress applied leads to its rupture) (Aleman *et al.*, 2007). On the other hand, when the proportion of gelatine is "low" (*i.e.,* less than the proportion required for gelation), gelatine molecules can only form local microscopic aggregates dispersed in the solution, which then flows with high viscosity (Figure 2) (Djabourov, 1991).

Between gels and thickened solutions, there are also intermediate systems, such as "debye", which are obtained by blending a gel in oil or in an aqueous solution (This vo Kientza, 2021a). Such systems can have various consistencies, such as "ointments" or "creams" (Mutimer *et al.*, 1956).

Sometimes compounds such as xanthan gum are named "hydrocolloids", but this is incorrect, as colloids are physical systems for which the molecules or polymolecular particles dispersed in a medium (*e.g.,* water) have at least in one direction a dimension roughly between 1 nm and 1 µm, or that in a system discontinuities are found at distances of that order (Everett, 1972; This, 2022). Also such products as xanthan gums are not "plant gelatine": gelatine is very specifically extracted from animal tissues (more precisely collagenic tissue), so that "plant gelatine" is an oxymoron. One should speak instead of "plant gelling agents".

How to use xanthan gums in practice? Examples of use, including concentrations, are given in Lersch (2023) or in Edwards-Stuart and Barbar (2021). It has simply to be added to an aqueous solution, with a proportion at will: with little thickener, little thickening is obtained, but with more thickener, there is more viscosity, as with the classical flour in hot water. For example, a ratio of 0.1-0.3% will make the consistency of a thin sauce, and for thicker sauces, a ratio of 0.3-1% is commonly used (Edwards-Stuart and Barbar, 2021). In order to make gels, one has to mix xanthan gum with other polysaccharides, and the order of magnitude of the minimum quantity of polysaccharides (for xanthan gum mixed with other polysaccharides, but also for other gelling agents) is 1-10% (w/w), depending on the particular gelling agents as well as chemical environment (pH, presence of ions, sucrose, etc.).

Finally, for xanthan gum as for other additives, the question of "hazard" has to be discussed. Here is an opportunity to observe that everything is dangerous, but the issue is reducing the risk, a notion involving exposure to the danger (EFSA, 2016). Among many possible thickeners and gelling agents, some are accepted by regulations after a thorough risk evaluation was performed. Lists of additives are regularly updated by international bodies (European Union, 2008): these include gelatines, pectins, potato starch, corn starch and rice starch, etc., all of which behave in different ways. There are also carob gums, gum arabic, guar gum, etc., as well as products less traditionally used in Western kitchens but introduced a few decades ago: gelling agents such as agar-agar, sodium alginate, certain carrageenans, etc.

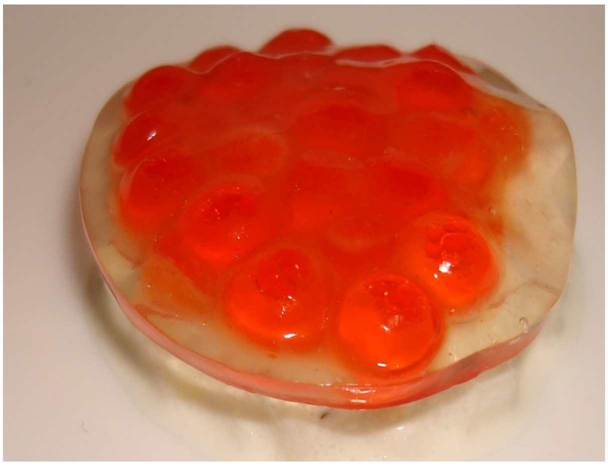

*Figure 3. Degennes,* i.e. *spheres with a liquid core and a gelled envelop were formed using calcium lactate dissolved in orange juice; drops of this liquid were then dropped in a solution of sodium alginate. In this picture, the spheres were then inserted in a gel, in order to make a system called a conglomele (This, 2019).*

At a time when a large proportion of citizens praise "natural products", it is worth observing that strictly speaking xanthan gum and other similar products are "artificial", because they have been produced. For example, gelatines are extracted from animal tissues, meat, tendon, etc., and pectins are extracted from plant tissues: fruit, vegetables, etc.; some other gelling agents are extracted from algae, such as agar-agar and carrageenans, and there are also thickeners produced by micro-organisms, such as xanthan gums. As a consequence, xanthan gums from different producers have different properties, as for other similar compounds, such as pectins, which are degraded when overheated (Sila *et al.*, 2005), or gelatines, which are different depending on their origin and processing (Eysturskard, 2009). As a consequence of the variability of the products, users have no general rules for determining the exact quantities to be used, and they have to make tests in order to determine how much xanthan gum is to be used in particular culinary conditions (acidity, temperature, etc.).

## 2. How can "herbal pearls" be made?

The second question concerned the production of "herbal pearls". This is a very vague question, again because of words, and more precisely because the word "pearl" is used in a metaphorical sense that can have different interpretations. According to the *Cambridge Dictionary*, a pearl is "a small, round object, usually white, that forms around a grain of sand inside the shell of a sea creature, especially an oyster. Pearls are valuable and are used to make jewellery" (Cambridge Dictionary, 2023).
Clearly, the chef who asked the question was thinking of another object. In the kitchen, for example, chefs are familiar with "Japanese pearls", tapioca, so that "herb pearls" could be obtained by cooking tapioca in a sauce with herbs (*e.g.* chopped parsley): the compounds responsible for the flavour, odour or colour of the herbs would migrate into the starch pearls, by diffusion or by capillarity (Aguilera *et al.*, 2004).
However, in molecular cooking, the word "pearl" has also been used for designing "degennes" (This vo Kientza, 2023), *i.e.* gelled or liquid spheres, bounded by a gelled membrane, formed by the reaction of sodium alginate with calcium ions $Ca^{2+}$ (Figure 3). Two main techniques are commonly used to produce these spheres with liquid inside: direct spherification and reverse spherification (Soprani *et al.*, 2021). In the first case, about 5% (w/w) sodium alginate is dissolved in an aqueous solution (in this case, a herbal solution), and drops of this liquid are deposited in an aqueous solution containing calcium ions (by dissolving calcium lactate in water, for example): contact between the sodium alginate and calcium ions leads to gelation, and immediate rinsing prevents excess calcium ions from migrating into the spheres formed, and causing the spheres to gel entirely. In the reverse process, sodium alginate is dissolved in water, and drops of the herbal sauce with calcium ions are added to the alginate aqueous bath.
Many other interpretations of "herbal pearls" can be envisioned: gelatine can be used to gel a "herbal solution", or herbal balls can be made from a herb omelette, using a melon spoon.

## 3. How can “tomato and date mousse” be made?

The third question concerns a "tomato and date mousse". How can such a food preparation be produced?
Again there are countless ways of achieving this. One possibility is to cook tomatoes with dates, to process all the ingredients in a food blender, to add proteins (*e.g.* powdered egg whites) and to whip: the result is a mousse. Gelatine also can be used: it has to be dissolved in the heated solution, and the foam that is created through whipping sets when it is stored at temperatures lower than about 36 °C. Another technique is to start by crushing the tomatoes with the dates, possibly while cooking, filter to recover a liquid, add egg proteins or a whole egg, put the liquid in a siphon and produce the mousse.
Contrary to a popular idea based on visual appearance, siphons produce foams rather than emulsions. Foams are colloidal systems in which gas bubbles are dispersed in a liquid (*e.g.* whipped egg white), whereas emulsions are dispersions of droplets of one liquid in another liquid (*e.g*. sauce mayonnaise, made of

oil droplets dispersed in the aqueous mixture of egg yolk and vinegar).
A simple optical microscope establish that the products delivered by siphons are indeed foams. Often the gas is nitrous oxide ($N_2O$) if an $N_2O$ cartridge is used), but it can also be carbon dioxide ($CO_2$), in which case the final product has a pleasant little fizz. Sometimes, the system can be both an emulsion and a foam if the liquid processed by the siphon is already an emulsion.
Other mousses can be obtained with less modern tools, *e.g.* by mixing the tomato and date purée with Italian meringue or whipped cream, for example, or by making a sabayon from tomato juice, date juice, sugar (sucrose) and whole egg.
In short, here again there are many ways to answer the question, because the name of the dish includes only three constraints: to include tomatoes, which are essentially water, to include dates, which are mainly made of water, and to include gas bubbles. In all cases, molecules are needed to stabilize the bubbles: egg proteins, for example, or proteins extracted from meat, plants or milk, or many other agents from the additive family.

### 4. How can lemon powder be made?

In order to make lemon powder, the fastest is probably to dip lemons in liquid nitrogen (indeed liquid dinitrogen, because the molecules $N_2$ are made of two nitrogen atoms), and then break the brittle frozen lemons. However not all chefs have liquid nitrogen. Dehydrators or freeze dryers are now more common types of equipment: a powder is obtained by placing slices of lemon on the trays. And when no such tools are available, lemon skins can be first put to in boiling water (three times), then cooked with a sugar (sucrose) syrup, before drying in an oven at 100 °C for some hours; after cooling, they can be ground into powder.
Different kind of solutions are to give the lemon flavour to powders such as starch, or "plating agents" (powders made of porous particles) such as *Pine Flow* or *N-Zorbit 2144*. The first one has a higher porosity and intrusion volume than the second and was found to have a greater capacity to hold oil: the oil holding capacities of *N-Zorbit 2044* and *Pine Flow* are about 100 and 400%, respectively (Domian and Cenker, 2013). The impregnating oil can be produced by macerating cut lemons in ordinary oil, or adding to oil a lemon flavouring (there many different kinds of such flavourings in the perfume and flavouring industry) and deposit the flavoured oil on a powdery base, such as starch: a "lemon powder" would be obtained.
It could have been discussed also for the previous and the next questions, but let us observe now that the names of food products are sometimes defined by regulations (wine, bread, meat, milk, etc.) or institutions such as the *Codex alimentarius* (FAO UN-WHO, 2023). Often, in order to know which product is designated by a name, consulting the regulatory texts is necessary: what is "corned beef", what is "white sugar", which ingredients are allowed in a marketed "mango chutney", etc.
This is not to say that such norms are perfect, far from it. For example, about flavours and flavourings, the *Discussion Paper for Flavouring Agents* recognized that "Natural flavours and natural flavouring substances are preparations and single substances respectively, acceptable for human consumption, obtained exclusively by physical processes from vegetable, sometime animal, raw materials either in their natural state or processed, for human consumption" (Codex Committee on Food Additives and Contaminants, 2004). However here the definition of the *Codex alimentarius* contradicts the common one: a flavour has always been and will remain as a synthetic sensation based on taste, odour, consistency, trigeminal stimulations

(This vo Kientza, 2021b). Also the use of the word "natural" is misleading, as it means indeed "what was not transformed by human beings": odorant preparations being prepared by the flavouring industry or by chefs, either extracted or synthesized, are indeed artificial.
Finally discussing flavourings calls for observing that "lemon flavourings" can be formulated in many different ways: the flavouring companies sell a variety of liquid products, or powders, with various flavours, depending on the particular mixture of odorant compounds used; users can choose between "fresh lemon", "baked lemon", "sweet lemon", "sour lemon", etc.

### 5. How can "espuma" be made? How can hot foam be made?

In Spanish, the word *espuma* simply means foam, or scum, or froth, and there is no reason to use the word *espuma*, as such systems were not invented in Spain. In molecular cooking, techniques of expansion using pumps or siphons were proposed to restaurants during the European FP5 Inicon program, as a technology transfer from the food industry, and chefs from many European countries began then using such systems.
As said before, a foam is a "dispersion in which a large proportion of gas by volume in the form of gas bubbles, is dispersed in a liquid [liquid foams], solid [solid foams] or gel [aerated gels]. The diameter of the bubbles is usually larger than 1 µm, but the thickness of the lamellae between the bubbles is often in the usual colloidal size range. The term froth has been used interchangeably with foam. In certain cases froth may be distinguished from foam by the fact that the former is stabilized by solid particles (as in froth flotation *q.v.*) and the latter by soluble substances" (IUPAC, 1972).
Culinary preparations are seldom pure foams, except for such systems as whipped egg, because the initial ingredients are generally not simple aqueous solution, but can be emulsions (*e.g.* oil droplets dispersed in the solution) or suspensions (with solid particles dispersed in a liquid). These complex systems are said to be “aerated”, and they can be better described using the “dispersed systems formalism” (This vo Kientza, 2021c).
Some aerated food products are classic, such as sabayons, meringues, certain sauces (béarnaises, hollandaises), but also soufflés, hot cakes or breads. The foaming is performed thanks to the natural foaming agents that are in the plant and animal tissues, such as proteins (from egg white, from animal or plant tissues) or phospholipids such as lecithins. Hence, there is no need for molecular cooking techniques to make hot foams, even if some tools, such as siphons, can be used.
Important information, in discussing aerated systems is the size of gas bubbles. Various tools produce foams with different bubbles. For example, stirring a rotating paddle can generate > 1 cm diameter bubbles, while siphons produce foams whose bubbles are invisible with the naked eye (radius < 0.2 mm). Finally one can observe that pumps with small nozzles, such as the ones used by pastry chefs to spray colorants, would be more sustainable than siphons, for which cartridges are seldom recycled.
As a conclusion of the answer to this question of hot foams, we have to observe that (1) knowing more chemistry and physics - in particular understanding the meaning of words borrowed from these fields - helps in recognizing unsuspected systems in traditional dishes, but also gives more control on their production; (2) the molecular and physical gastronomy analysis of food systems is the key of reasoning in terms of functionality of ingredients. For example, observing that gelatine is a protein, one can start from any aqueous solution (*e.g.* raspberry juice), heat it to dissolve gelatine, and whip while cooling: the foam that is produced will gel into a food system called a "würtz" (This, 2009). This is a cold gelled foam, but replacing gelatine by thermocoagulable proteins such as animal

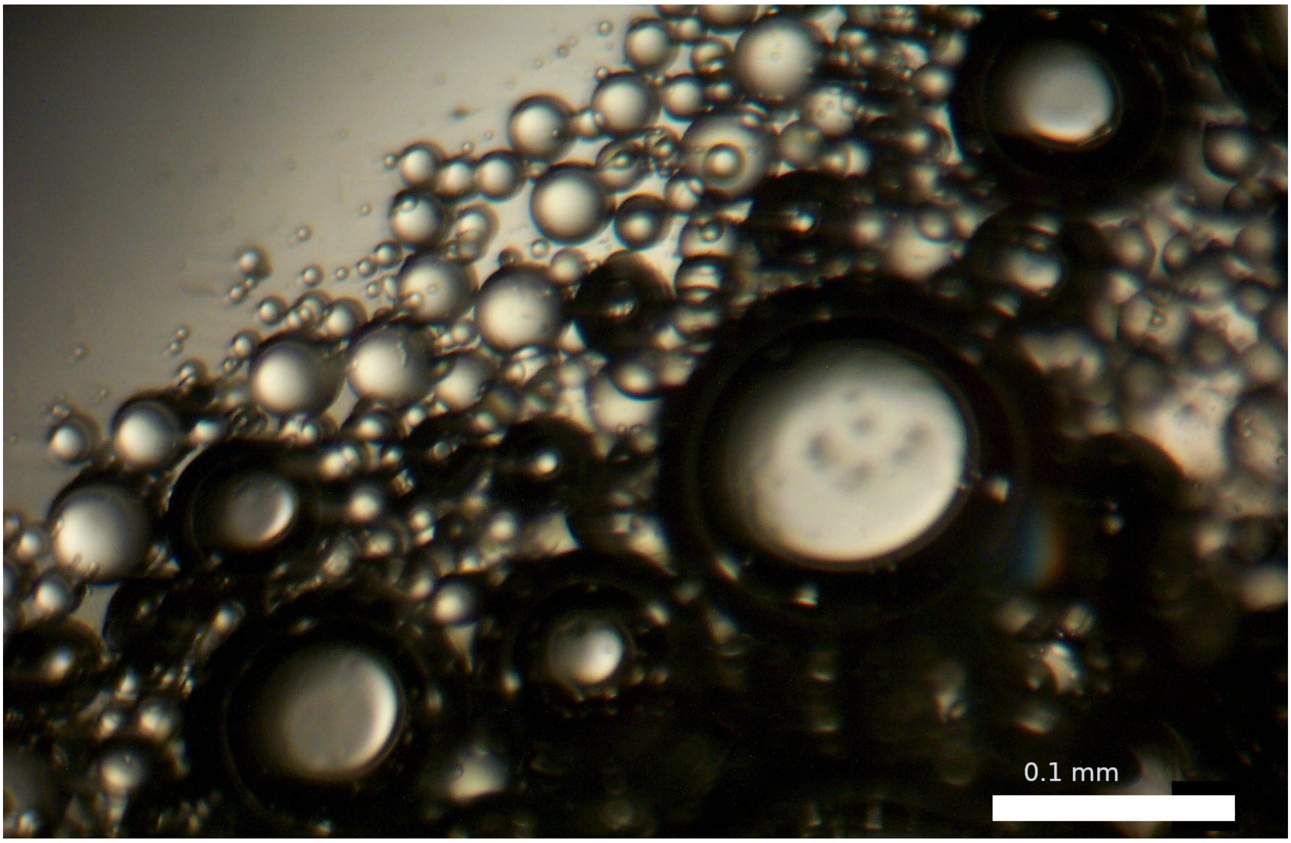


*Figure 4. When an egg white is first whipped, and then oil is added while whisking, an emulsified foam can be obtained. Here, the system is observed using an optical microscope. The dark spheres are air bubbles, and the smallest transparent spheres are oil droplets. The diameter of the biggest dispersed structures is about 0.1 mm.*

proteins (actin, myosin, ovalbumin, etc.) will lead to hot aerated gels, still with the flavour that one wants.

### 6. How to make a "vanilla emulsion"?

The expression "vanilla emulsion" is as imprecise as the previous systems that were discussed before. As an emulsion (see above) is a colloidal system made of droplets of one liquid dispersed in another liquid, no "vanilla emulsion" can exist *stricto sensu* because vanilla is not an oil, and it is not an aqueous emulsion either. In the question from the chef, "vanilla emulsion" should be replaced by "emulsion with vanilla flavour". And this new question has no answer, because the flavour of an emulsion will never be the exactly the same as the flavour of vanilla, with exactly the same odour, taste, trigeminal sensations, and others orosensory compounds (Schwartz and Hofmann, 2009). The best that can be made is an emulsion with a flavour similar to vanilla, as a photo of a painting is similar to the painting, more or less closely.

In order to make such an emulsion, "oil" (by oil, physical chemists mean any hydrophobic liquid), "water (any aqueous solution) and surfactants are needed. In the vanilla context, a vanilla aqueous extract can be made by macerating vanilla pods in water, extraction hydrophilic compounds. And a "vanilla oil" can be produced by maceration, infusion or decoction of vanilla pods in oil or in any other liquid fat (*e.g.* melted butter), extraction hydrophobic compounds, including odorant ones.

Concerning surfactants, the list of accepted additives contain many candidates, such as lecithins, diphosphates, polysorbates, carrageenans, guar gum, polysorbates, celluloses and cellulose derivatives, mono- and diglycerides, sucrose esters and sucroglycerides (European Commission, 2023). In the kitchen, proteins or phospholipids are often used because they are naturally present in plant or animal tissues: any ground plant or animal tissue releases water and surfactants, so that oil can be emulsified. This is the mechanism of the traditional sauce aioli, made of crushed garlic into which olive oil is emulsified, and this is the principe of "ollis", *i.e.* generalizations of aoili, but with any ground plant or animal tissue (This, 1997).

Finally, energy is needed to make emulsions, dividing the oil in tiny droplets that are dispersed in the aqueous solution. Traditionally forks, whisks, mortar and pestle are used, but mixers make firmer emulsions because they give more energy and overcome better surface tension, generating smaller droplets. In chemistry laboratories, ultrasonic probes are common, but in spite of proposals made for decades, they remain very rare in kitchens.

Let us end this long paragraph by considering a proposal that was made in the 1990s, of a system that was named "geoffroy" (This, 1997): an egg white is used as it contains water (90%) and proteins (10%, around 370 kinds) (Shi *et al.*, 2023); if oil is added in while whisking, air bubbles are first introduced with oil droplets, and an emulsified foam is obtained (Figure 4).

Adding more oil makes the bubbles disappear; the emulsified foam turns into a white - somehow aerated - emulsion. The preparation is very smooth, white and flavourless, so it can be given any flavour, such as vanilla. The emulsion can be turned into a dessert, adding sugar: sucrose dissolves in water, up to a limit of 960 g of sucrose per kilogram of water. The vanilla geoffroy can be served as it is, but it can also be cooked in a microwave oven until expansion is observed, so that the proteins in the egg white coagulate, producing an expanded, chemically gelled emulsion known as "gibbs" (This, 2009).

*Figure 5. This green "dirac" was obtained by frying a 20% protein aqueous solution, added with oil salt, glutamate monosodium, piperine, green food colorant, D-glucose, and 1-octen-3 ol (This vo Kientza, 2021).*

## 7. What is a "protein batter"?

Finally about "protein batters", again the name does not describe only one particular product, but allows imagining many possibilities. For example, adding 10 g of egg white powder in 100 g of water makes a batter that has the properties of egg white: it can be whipped into a white foam, or cooked, producing a result very similar to cooked egg white. With a higher proportion of water, the batter becomes less viscous, but still coagulates, until the proportion of proteins is less than 5%; with more proteins (20%), thermocoagulation generates products that can have the hardness of meat. This batter behaves like the one that would be made from flour and water, except that proteins are present instead of polysaccharides.

So far, only egg proteins were mentioned, but there are proteins in many other products, both in animal tissues or products (*e.g.* milk proteins) and in some plants tissues, such as pulses (Shevkani *et al.,* 2019). Today plant proteins again can be found under the form of powders (white powders when they are pure) and they can often be used as explained for egg white.
It was not part of the question, but how can a protein batter be used? If it is put in a syringe and deposited in a hot medium (boiling water, hot oil), some "spaghetti" are obtained from the protein batter; if deposited as a layer that is heated, coagulated sheets can be produced, etc. If the proteins have been chosen in such a way that they can coagulate, then the equivalent of meat (a "dirac") can be made, at least from the point of view of consistency (Figure 5) (Gagnaire, 2021). Such "pancakes" can be improved, for example by spreading the protein batter, strewing it with a fork, cooking it, rolling it on itself into a sheet and obtaining a kind of surimi, as was done in 2012 by the chefs Ismail Osorio, Erik Ayala-Bibriesca, and their students from the Institut technique du Québec (ITHQ), in Montréal (Canada).
Any flavour can be given to all these products. In the experiment described above, "water" was used as the liquid, but any aqueous solution will do: tea, coffee, orange juice, tomato juice, wine, stock, etc. And moving to "synthetic cooking" (the technique used by the culinary art called “note by note cooking) gives even more possibilities (This, 2014). Indeed flavour is the synthetic sensation including colour, consistency, temperature, tastes, odours, and spiciness and freshness, etc. One should therefore not forget, before cooking or before use, to add compounds to the protein batter in order to create colour, flavour, odour, etc.

## 8. Conclusion

The chemical and physical analysis of culinary systems not only makes it possible to understand the constitution of classic culinary preparations, but it is also the basis for innovations, demonstrating that the results of natural sciences are a condition for fruitful technological work. Often it is useful to use the right names for objects and mechanisms, in order to ask more precise questions and find the answers to these questions more easily.

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