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The science of molecular gastronomy and the art of innovative cooking

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Since the creation of the scientific discipline that we called 'molecular and physical gastronomy' (later shortened in 'molecular gastronomy') in 1988, there has been much confusion between the science of molecular gastronomy and the art of modern cooking, probably because the word 'gastronomy' has been sometimes wrongly interpreted as 'cooking fine food'. The genuine definition of gastronomy, introduced in the 19th century by the French lawyer Jean-Anthelme Brillat-Savarin [1], is actually the study of human nourishment. In other words, molecular gastronomy is performed by scientists in chemistry, biology or physics laboratories, where there are no pans, but rather analytical equipment such as nuclear magnetic resonance spectroscopes, mass spectrometers or gel electrophoresis; and 'molecular cooking', the first important application of molecular gastronomy, is a modernized culinary technique [2]. Today, a new culinary technique called 'note by note cooking' is being developed in many countries [3]. It is for food the equivalent of synthetic music for music. Here, we shall answer some of the many questions that note by note cooking is generating.

What is molecular gastronomy?

Like all natural sciences, molecular gastronomy is based on experiments and calculation, in order to explore the mechanisms of phenomena [4]. In this particular case, the field studied is not living systems as in biology, or objects of the big universe as in astrophysics, or molecules as in chemistry, but rather the making of food (indeed 'dishes') from food ingredients.

For example, when 'meat stock' is obtained by thermal processing of muscular tissues of animals in water, a question is to know how compounds move from the inside of meat towards water, and possibly how water can -or cannot- move towards the inside of meat with possible chemical modifications. The same kind of questions hold for stocks and broths made from plant tissues, or for beverages made from leaves of *Coffea* (coffee) or of *Camellia sinensis* (tea), and it is surprising that in spite of many studies on the kinetic evolution of such systems, the mechanisms of extraction are still poorly known. In the case of tea, for example, there are many articles about tea making, about tea composition, about authenticity or variations of the beverage composition according to the geographical area where the plant is grown [5], but the mechanism of release of the various solutes that characterize the beverage remains unknown.

Such questions, which are investigated by molecular gastronomy, show why this field is not to be confused with technology and engineering, that is, the application of sciences for improving technique. The goal of molecular gastronomy is to focus on mechanisms in the hope of making discoveries (and not inventions, as for technology).

The eradication of culinary superstitions

The old superstitions about gods sending storms, or being responsible for spreading diseases, were (unfortunately only partly) overcome by scientific advances. In the kitchen, as well, molecular gastronomy was important, because strange ideas remained and even mistakes have been taught in culinary schools.

For example, it has been said that 'mayonnaise sauce fails when the slightest trace of egg white remains with the yolk', or when it is prepared by women having their period [6]; or it was said that 'egg whites make a bigger volume of foam when whipped always in the same direction'; or cooks thought that searing meat would prevent juices from leaking out when the meat is grilled. All these superstitions can be easily refuted by simple experiments and measurements. Indeed, an emulsion can be obtained by whipping oil in an egg white; and straightforward measurements show that meat shrinks when it is cooked and juices are ejected whatever the thermal treatment of the surface.

More than 25 000 such 'culinary precisions' have been collected in the French culinary literature, and for by now 19 years, we have been experimentally testing them. Interestingly, we observe that many are wrong. The curriculum of French public culinary schools was changed, as many wrong ideas were being taught since the beginning of the 20th century. For example, there was a wrong theory that distinguished 'cooking by concentration' (roasting) and 'cooking by expansion' (for stews), but there is no concentration of juices when meat is roasted (on the contrary, collagen denaturation and consequent contraction leads to juice ejection), and meat does not expand (but contracts) when boiled in water. As a result, molecular gastronomy courses have been introduced for all professors teaching in French public culinary schools.

Technical applications of molecular gastronomy

An early technical application: molecular cooking

Sound ideas on the mechanisms underlying some phenomena can lead to the improvement of related techniques. Following the definition of molecular gastronomy as a scientific discipline in 1988, the development of new culinary techniques involving the use of hardware from chemical laboratories in the kitchen gave birth to a new art named 'molecular cuisine' (name given in 1999). While cooking remained a very traditional activity, laboratories were equipped with very efficient appliances. If one wants to make a foam, for example, why use a traditional tool that does not foam well? The same reasoning holds for emulsions, suspensions, and most physical systems [7].

Molecular cooking, the technique on which molecular cuisine is based, was defined as 'a cooking approach using modern tools', and more precisely tools that were not present in kitchens before the 80s. Chefs progressively introduced the use of siphons, liquid nitrogen, rotary evaporators, decanting bulbs, thermocirculators, ultrasonic probes, and more. At the same time, 'new' (for Western chefs) gelling and foaming agents such as agar-agar, carraghenans, alginates and lecithins were introduced.

More recent applications: note by note cooking

While molecular cooking was developing all over the world, a much more important technical application of molecular gastronomy was proposed in 1994 under the name 'note by note cooking' (given later). In brief, note by note cooking is the preparation of dishes (food) from pure compounds, just as synthetic music can be obtained from sound waves of defined frequency.

The historical comparison of the relationship between science and musical art, on one hand, and science and culinary art, on the other hand, makes the crazy idea (chemicals in food!) of note by note cooking more obvious. Let us begin by considering the classical versions of these two arts. Initially, music was produced by playing musical instruments, just as food was produced using plant and animal tissues. Later, the work of the French physicist Joseph Fourier (1768–1830) revealed that sounds could be analysed, and considered as superimposition of waves with defined frequencies. In parallel, Jean d'Arcet, Antoine Laurent de Lavoisier, Augustin Parmentier, and other eminent chemists progressively discovered that food ingredients are physical and chemical assemblies of organic and mineral compounds. However, in recent times, the history of the two arts diverged: whereas synthetic music was produced, through the assembly of sound waves of defined frequencies, using electroacoustic systems, nothing comparable was done for food. As a matter of fact, in 1994 the proposal of making synthetic food aroused a wave of scepticism and fear, because – it was said – this would lead to an illicit adulteration of products. Even today, the proposal sometimes triggers violent reactions in culinary circles, where note by note dishes are accused of not being 'real food'.

Synthetic food

Synthetic food, called 'note by note food' after 1997, is food that has been obtained using pure compounds, processed and combined by the cook to create all aspects of food, such as shape, consistency, colour, odour, taste, trigeminal sensation (for texture perception), nutritional properties and temperature. More generally, all aspects of food are taken into account, including newly found sensorial modalities. For example, it was found that humans can detect the taste of calcium through the T1R3 receptor [7], and that lactisole can inhibit the receptor [8]. More recently, fatty acids were found to have different tastes depending on their chain length, and the term 'oleogustus' was introduced for long chain fatty acids [9].

Note by note dishes are increasingly common, in part because there has been an international promotion of note by note cooking to chefs of many countries, but also because the International Contests for Note by Note Cooking provided opportunities to inspire the creation of recipes and their distribution. An example of a recipe is given in Box 1.

Gibbs

1 In a vessel, put about two spoons of water
2 Add one tea spoon of proteins that can thermo-coagulate (e.g. egg white proteins)
3 Whip (using a traditional whisk) while adding oil, as for making mayonnaise sauce (i.e. an emulsion)
4 Add sugar, colourant, citric acid, salt
5 Distribute the emulsion in cups
6 Cook in a microwave oven until an expansion is observed
7 Serve hot.

The recipe given here, named after the American physical chemist Josiah Willard Gibbs, is only the backbone of a recipe for culinary art. In particular, the odourant part of the dish is neglected, but it is easy to improve the recipe by adding as many ingredients as one wants. For example, an interesting odour between freshly cut grass and virgin olive oil can be obtained with cis-3-hexen-1-ol, while an odour between cherry and almond can be obtained using benzaldehyde. These are only two possibilities out of approximately 7000 known odourant compounds from plants [10]. Combinations of such compounds can be used, and entirely new flavours can be produced, which is quite exciting for people who love food.

Savoury recipes can be easily developed as well. Indeed, this year's contest focuses on dishes called 'diracs' (after the British physicist Paul Dirac), that intend to reproduce the composition of meat, that is, about 70% proteins, 15% water and lipids (of course, there is no reason to stick to this proportion). Using similar techniques to those used for surimis, a wealth of different consistencies can be obtained, such as gels, foams, emulsions, suspensions, as well as a combination of those. Again, the flavour is exactly how you decide to make it. (Box 2).

Dirac

1 Mix 75% water and 25% egg white proteins
2 Emulsify oil
3 Add salt, glucose, colourant, monosodium glutamate, a dilute solution of diallyl disulphide, of methional, of piperine
4 Add a batter obtained by heating water and amylopectin (you can use corn starch)
5 When the mixture is cooled down, pour it as a thin layer on a flat surface, and scratch the surface with a fork
6 Cut squares and cook in a microwave oven
7 When cold, roll in cylinders.

It is worth noting the difference between 'pure note by note cooking', where pure compounds are used as ingredients, and 'practical note by note cooking', for which chemically simple mixtures can be used as well. For example, while corn starch (including amylose and amylopectin) and sunflower oil (a mixture of triglycerides) are not pure compounds, they are often used in practical note by note cooking for matters of simplicity. Similarly, mixtures of polyphenols extracted from grapes and chlorophyllins (instead of pure chlorophyll a, a', b, or b') are often used. Again, a comparison with music can be made: you can make music by assembling waves into specific sounds, that are used for making a melody, but this requires the skills and knowledge of highly trained technicians; however, musicians often use simple synthesizers that make it easy to make music, at the expense of possibilities.

Some of the compounds used as ingredients for note by note cooking are synthesized, such as benzaldehyde or methional, or even vanillin, since this is the simplest and cheapest method. However, for many complex compounds that are nutritionally important, plant extraction is the most obvious and practical way. Indeed, synthesizing vitamine B12 (α-(5,6-diméthylbenzimidazolyl)cobamidcyanure) required the effort of 91 post-doctoral fellows and 12 Ph.D. students from 19 different nations! While this was an opportunity to explore organic chemistry, it would be useless for practical purposes.

The use of cell culture systems in synthetic food

The use of cell culture systems for food preparation, that is the reproduction of meat, is controversial [11]. In 2013, the first laboratory-grown beef patty was produced and consumed. One argument among many in favour of such techniques is that it circumvents the slaughtering of animals, and it has a fast production rate (based on exponential growth due to cell division). However, many countries are regulating the use of the term 'meat' to avoid confusion between cultured tissue and muscular tissue from animals. In note by note cooking, reproductions of meat can be obtained readily by using the chemical composition (mainly water, proteins, and lipids), organized so that different microstructures can be made. And probably the control of consistency is much easier.

Conquering famine with synthetic food

Humans are facing the challenge of having to feed ten billion people by 2050. We believe that synthetic food could be a practical way of addressing this problem. Indeed, part of food spoilage is due to the fact that plant and animal tissues are mainly made of water, so that transporting them from production sites to cities (where most people live now) goes along with mechanical or microbiological damage, generating spoilage, and a reduction of the efficiency of the agricultural production. In addition, the shipping is a waste, as energy is needed both for transportation and refrigeration. Fractionation at the production sites (using membrane systems) would have the advantage of avoiding the transportation of water, avoiding the damage of tissues, making innovative products with longer shelf lives, and levelling the prices (because of the possibility of storing the fractions). And, last but not least, a new culinary art can develop!

Potential hazards of synthetic food

For surviving, we need a lot of compounds, such as vitamins and oligo-elements. All of them have to be present in what would be our daily note by note food, as they are in postoperative parenteral nutrition, which has been successfully used for about five decades [12]. Now, if practical note by note cooking is used, starting from fractions recovered by the fractionation of traditional food ingredients, the diet should be nutritionally complete, as long as the bioactivity of the compounds is preserved.

Of course, it would be unreasonable to pretend that note by note cooking is the only possibility of development for food security. Many questions remain about feeding humans solely through this method, because nutritional science today cannot say how the food should be designed, chemically and physically, for safe long-term diets. These points should be investigated, in the next decades, but with a rational mind, and without *a priori* ideas and ideologies, such as those which base attacks against wrongly called 'ultra-transformed food'.

The cook of the future

Already back in the 80s, at the very inception of molecular cooking, I was asked whether the cook of the future would have to have a degree in biochemistry. The question came when I proposed to use thermocirculators for low temperature cooking. At the time, such hardware could only be found in laboratory hardware catalogues, and the cooks who used them were considered pioneers (that they were). Nevertheless, today such equipment designed for the kitchen exists.

Chefs from all over the world showed that note by note recipes are equal to traditional recipes, in that you simply need to follow the protocol. However, whether you need a degree in biochemistry for designing note by note recipes is a different question. A difference must be made between pure note by note cooking and practical note by note cooking. My guess is that, because pure note by note cooking is too difficult, practical solutions will be found, so that the public will have an easier access to food preparation. And also, it is likely that note by note cooking will not be the only way of preparing food. For some time (decades?), traditional cooking will survive.

One can also look at the reverse side of the question. Is a chemist working on molecular gastronomy a good cook? Science and cooking are different activities, with different goals and different methods. Personally, having an utmost passion for chemistry (and also mathematics and physics) since the age of 6, I am the happier man when I am in the laboratory, where instead of pots and pans, I can use scientific approaches, such as NMR spectroscopy, IR, UV, or mass spectrometry to analyse culinary phenomena, like the release of compounds from plant tissues during thermal processing in water, or in meat. My ability to cook has nothing to do with my ability to do science.

Certainly scientists may love food... but they do not necessarily have to be good at cooking, unless they train in the three components of cooking: technique, art and sociality, the latter being probably the most important one, because making and sharing food has important roots in human evolution. However, for science in general, and molecular gastronomy in particular, the goal is not achieving excellence in cooking, but producing knowledge, based on which applications (in education and technique) can be developed.

References

1 Brillat-Savarin JA (1825) *La physiologie du goût*. Chez l'auteur, Paris.
2 This H (2009a) Molecular Gastronomy, a chemical look to cooking. *Acc Chem Res* **42**, 575–583.
3 This H (2008). Descriptions formelles, pour penser et pour la formulation. *L'Act Chim* **322**, 11–14.
4 This H (2009b) Science, technologie, technique (culinaires): quelles relations?, Cours de gastronomie moléculaire N°1. Editions Quae/Belin, Paris.
5 Perva-Uzunalic A, Skerget M, Knez Z, Weinreich B and OttoF Gruner S (2006) Extraction of active ingredients from green tea (*Camellia sinensis*): extraction efficiency of major catechins and caffeine. *Food Chem* **96**, 597–605.
6 This H (2010) Les précisions culinaires, Cours de gastronomie moléculaire N°2. Editions Quae/Belin, Paris.
7 This H (1995) La gastronomie moléculaire. *L'Act Chim* **1995**, 42–46.
8 Tordoff MG, Alarcon LK, Valmeki S and Jiang P (2012) T1R3: a human calcium taste receptor. *Scientific Rep* **2**, 496.
9 Laugerette F, Gaillard D, Passilly-Degrace P, Niot I and Besnard P (2006) Do we taste fat? *Biochimie*, https://doi.org/10.1016/j.biochi.2006.10.011
10 Dunkel A, Steinhaus M, Kotthoff M, Nowak B, Krautwurst D, Schieberle P and Hofmann T (2014) Nature's chemical signatures in human olfaction: a foodborne perspective for future biotechnology. *Angew Chem Int Ed* **2014**, 7124–7143.
11 This H (2016) What can "Artificial Meat" be? Note by note cooking offers a variety of answers. Notes Académiques de l'Académie d'agriculture de France/ Academic Notes from the French Academy of Agriculture, **6**, 1–10.
12 Dudrick SJ (2003) Early developments and clinical applications of total parenteral nutrition. *J Parenter Enteral Nutr* **27**, 291–299.

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