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Note de recherche

What can "Artificial Meat" be? Note by note cooking offers a variety of answers

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Résumé :
L'analyse du système "viande" du point de vue physique et chimique permet d'envisager de nombreuses possibilités de reproduction de ce système, en vue de faire ce qui doit être nommé de la "viande artificielle". La technique nommée "cuisine note à note", qui consiste à produire des aliments à partir de composés purs (plutôt que des ingrédients alimentaires traditionnels que sont principalement les tissus animaux et végétaux) permet bien d'autres possibilités de reproduction que la seule culture *in vitro* de cellules musculaires. On examine comment la cuisine note à note peut élaborer les aliments, et quelles questions scientifiques et technologiques elle pose. Notamment on envisage la possibilité de construire la viande (en particulier la "viande artificielle) à toutes les échelles, de l'échelle moléculaire à l'échelle macroscopique.

Abstract:
The physical and chemical analysis of "meat" leads to many different options for making "artificial meat", depending on which aspects of natural meat is chosen for the reproduction. "Note by note" cooking, i.e. making food from pure compounds rather than from traditional food ingredients such as plant and animal tissues, offers many more possibilities than simply growing muscular fibers *in vitro*. It will be explained here why this new culinary technique was suggested for creating artificial meat, how NbN dishes can be elaborated, and which new scientific and technological issues NbN raises. In particular, the possibility of elaborating food at any scale is discussed, and new varieties of gels are discussed.

Keywords:
molecular gastronomy; note by note cooking; bioactivity; dynagels; statgels; DSF; artificial meat.

Mots clefs :
Gastronomie moléculaire, cuisine note à note, bioactivité, dynagels, statgels, DSF, viande artificielle.

Note de recherche

Introduction

The predicted increase in the world population creates new challenges, one of which being the threat of worldwide food shortage (United Nations, 2004). In order to feed 9 to 10 billion human beings in 2050, some new technologies such as genetically modified organisms have been suggested, but though they may allow for an increase in the productivity of agriculture (Tilman *et al.*, 2002), their sustainability is the object of some amount of controversy (Fresco, 2001).

Another promising way of improving the efficiency of food production could be the curbing of food spoilage, possibly reaching 30 % in some countries (FAO, 2013) and perhaps up to 45 % in developed countries (NRDC, 2013): even if such figures are discussed, more food would be available if we could avoid damage to food ingredients during transportation from farms to homes (Gustavsson *et al.*, 2001) or during storage before consumption (FAO, 2013).

Because food ingredients are physical and chemical systems (This, 2013a), "spoilage" may include an alteration either in their physical structure at particular physical levels – macroscopic, microscopic, nanoscopic or molecular – or in the chemical nature of the compounds present in food ingredients (Jamet, 2016). Moreover, traditional food ingredients being mainly made of a large quantity of water (up to 99 % in some) (Belitz *et al.*, 2009), their transportation can be considered a needless waste of energy: if water were removed from food ingredients at the farm (by fractionation and cracking), the energy spent in transportation would be reduced drastically (Yoshikawa, 2016).

As well the chemical integrity of food ingredients would be preserved, as dry products are much more resistant to micro-organisms (New Zealand Food Safety Authority, 2005). Of course, at the other end of the food chain, cooks (in homes or in restaurants) and food industries would have to reconstitute dishes, starting from the various compounds produced during water removal.

Here "water removal" is not restricted to drying in air or by heating, or even to freeze-drying. Because of the high latent heat of water (The Physics Hypertexbook, 2013), drying food ingredients is energy-consuming, but filtration techniques (nanofiltration, microfiltration, direct or reverse osmosis...) can be helpful in removing water from food ingredients efficiently, as well as making fractions at the same time (Gésan-Guiziou, 2007; Van Audenhaege *et al.*, 2014).

Such filtration techniques are already in use for milk and wheat (Van Audenhaege *et al.* 2012), but they could be applied to any plant or animal tissues, leading to new fractions, such as total phenolic fractions already produced under an INRA license ("Provinols") by some companies (INRA, 2013). Depending on the level of purity needed, sequential filtration and cracking could allow for more and more different fractions, which could in turn be used as new food ingredients for the culinary technique called "note by note cooking" (NbNC) cooking (This, 2013b).

A new culinary technique

NbNC was first introduced in 1994, when "molecular cooking" was spreading in the professional culinary world (Ashley, 2013). It is different, as the goal is no longer to introduce new tools (siphons, rotary evaporators, water heating circulators, liquid nitrogen...) for transforming traditional food ingredients (Inicon, 2016), but rather to make food with new ingredients, i.e. pure compounds (there is also a clear difference between NbNC and the scientific discipline called "molecular gastronomy", as NbNC is producing food, whereas molecular gastronomy is the scientific study of phenomena occuring food production and consumption) (DIT, 2013). Producing food using pure compounds or new fractions obtained by fractionation or cracking of plant or animal tissues can lead to new dishes, which is indeed what many creative cooks are looking for (ESCF, 2013). In particular, the issue of "artificial meats" has to be discussed (below) in view of times when meat production will become insufficient (Combris, 2012) or if animal consumption becomes socially unacceptable.

A comparison of NbNC with electro-acoustic music could be helpful in order to better appreciate the potential interest of NbNC for the culinary art practitioners: electronic music, developed mainly after the middle of the twentieth century (Dunn, 1992), when musicians and acousticians used computerized and electronically-generated sound waves of specific wavelengths to compose music, but it only became popular when user-friendly technologies were developed; synthesizers are widely used today (a *Google* search on the word "music+synthesizer" yields more than 30 million results).

The same kind of development could occur with NbNC: today, cooks find it difficult and time consuming to use pure compounds ("pure NbNC") in order to build up food in all its aspects (nutrition, shape, consistency, color, taste, smell, etc.), but in the future some particular mixtures of compounds could be used more easily ("practical NbNC").

Whatever the particular technique (pure NbNC ou pratical NbNC) being used, tests already carried out with chefs showed that it is probably easier to design first the shape, then to choose the consistency of the product, and only later to add "bioactive compounds", i.e. compounds acting on receptors for color, taste, smell and trigeminal sensations (This, 2012).

The compounds used can be chosen in the list of already consumed compounds, which are part of traditional food ingredients or food, and from this technical point of view, it is not important that such compounds are produced by fractionation of plant or animal tissues, or by chemical synthesis; all what is needed is that the compounds are "food grade", which means edible with no harmful impurities (of course, the issue of price and sustainability of the production of such compounds will have to be considered in the future) (AFSCA, 2011; FDA, 2016).

For example, for consistency, water, polysaccharides, proteins, lipids are of primary choice. For taste, mineral salts, saccharides or amino-acids can be used in lower concentrations, but some interactions between consistency and taste have to be considered, as shown by the experiment of adding sucrose to dough made of flour and water (Feillet, 2000). For odor and color, the choice is easier as essential oils or flavorings, and colorants have long been in use by food companies (Surburg and Panten, 2006).

However the advantage offered by NbNC would be to provide cooks with the possibility to make up their own mixtures, from pure odorant compounds dissolved in the appropriate (edible) solvent (*e.g.* oil). Let us observe immediately that a mixture of the main compounds present in meat would already be "artificial meat". Of course, this would lack many characteristics of real meat, but similarly, a photographic reproduction of a painting lacks the texture of the painting, varnishes, and other characteristics of the real painting.

Building new food

The fact that dishes are physical and chemical systems with "bioactivity" means that during consumption dishes release compounds having receptors in the body (nutrition, sensory appreciation, etc.) (This, 2012). For the exploration of such release, quantitative parameters called absolute (potential and actual) bioactivity, dynamic bioactivity, matrix effects have been introduced. The particular organization of compounds in food determines these bioactivity indexes as well as matrix effects, so that the study of NbNC involves looking for the relationship between multi-scale organization of compounds and bioactivity parameters (Axelos, 2013). Contrary to traditional food, where the consistency is often obtained by a modification of the consistency of the food ingredients, the consistency of NbN food can be designed entirely. In this regard, the formalism proposed for the description of dispersed systems (DSF) is a key tool as it considers both the dimension of the constituents which appear at any scale, as well as the nature of the phases; operators describe the geometrical relationship of the objects (This, 2007; This, 2009; This *et al.*, 2013).

Using this formalism, building food at any scale (rather than simply a multi-scale built food) is possible. For example, let us consider the making of a dish P_1 using several macroscopic parts $P_{1,1}$, $P_{1,2}$,..., $P_{1,n(1)}$, themselves made of parts on the next scale, and so on. Using the operators of DSF, this dish could be described by the formula:

$$P_1 = P_{1,1}\ op_{1,1}\ P_{1,2}\ op_{1,2}\ P_{1,3} ...\ op_{1,n(1)-1}\ P_{1,n(1)} \quad (1)$$

where $op_{i,j}$ are chosen in the list of DSF operators and any $P_{1,i}$ is itself made of parts:

$$P_{1,i} = P_{2,i,1}\ op_{2,i,1}\ P_{2,i,2}\ op_{2,i,2} ...\ op_{2,i,n(2,i)-1}\ P_{2,i,n(2,i)} \quad (2)$$

And so on for any “part”, until the molecularscale is reached.

From this description, many observations can be made. For example, at the microscopic level (between 10^{-6} m and 10^{-3} m ; this covers more than one scale), the parts are generally colloids (IUPAC, 2013). Moreover, not all scales need to be considered. For example, when the first “reference size” ranges from 2.10^{-2} to 2.10^{-1} m, the second scale should be

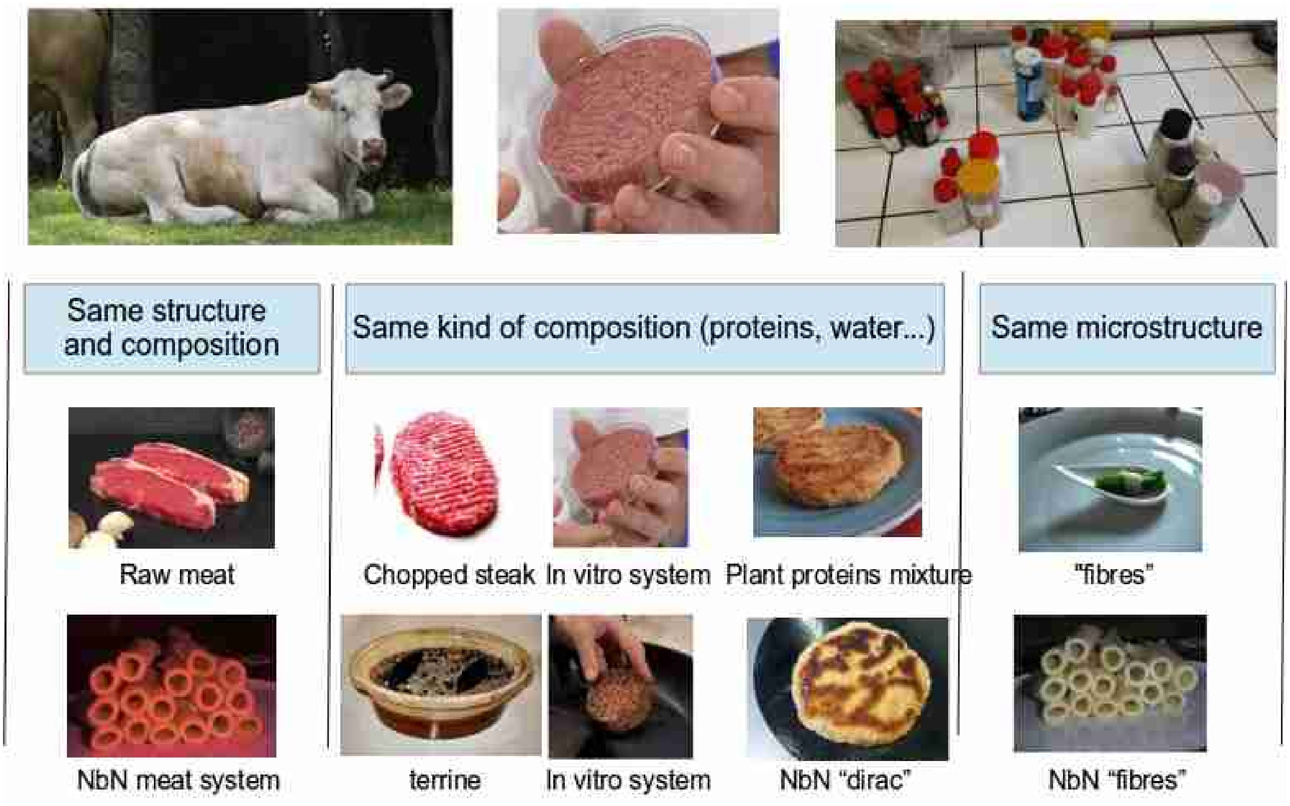

Figure 1. Many different systems can be made when the meat composition and/or structure is "reproduced". In vitro *systems obtained by cultivation of muscular fibres is only one possibility among many.*

between 2.10^{-3} and 2.10^{-2} m, the third one between 2.10^{-4} and 2.10^{-3} m, and so on down to 2.10^{-10} and 2.10^{-9} m (molecular level). It is perhaps not useful to describe the dish in all these scales (9 orders of magnitudes), because some objects span over two scales, and we suggest to consider only sizes instead, ranging from 10 cm to 1 mm ("macroscopic", scale 1), then from 0.1 mm to 0.001 mm (= 1 µm) ("microscopic", scale 2), then from 1 µm to 0.01 µm ("nanoscopic", scale 3), and then from 10 nm to 0.1 nm ("molecular", scale 4) (Sci-Tech Dictionary, 2003).

The downward analysis of food is a preliminary step for the understanding of the behavior of food systems that would be built from molecular up to macroscopic level, at all scales. Using the right compounds, and the known physical and chemical laws, it is possible to envision a wealth of possibilities, among which “artifical meats” are one possibility.

Artificial meat

The previous discussion showed that the scope of possible systems that can be built from pure compounds is very large. In particular, systems reproducing various aspects of meat can be produced. However the terminology “artificial meat” has to be discussed first. On the one hand, meat is defined as “the flesh of an animal when it is used as food”, the flesh being “the soft part of the body that is between the skin and the bones” (Cambridge Dictionary, 2016); for the Codex alimentarius, the definition is slightly different (“all parts of animal that are intended for, of have been judged safe and suitable for, human consumption”) (Codex alimentarius, 2016). On the other hand, “artificial” means “made by people, often as a copy of something natural”. We shall not discuss here the fact that most animals used as food are seldom “natural” strictly speaking, because they were selected by the human kind after domestication (Digard, 2009); rather the discussion is focused on “artificial”, because there can be copies of different kinds, physical or chemical, and with different degrees of similarity compared to the original meat. The muscular tissue of animals is made of muscle fibers, i.e. elongated cells grouped in bundles and superbundles by the collagenic tissue, with vessels and fat deposits (Listrat *et al.*, 2016). The muscular fibres include water and proteins such as actins and myosins. This system can be reproduced physically, chemically, or from both points of view simultaneously (Figure 1).

Firstly, from the chemical point of view, any system having a chemical composition close to the one of meat can be considered as “artificial meat”. For example, a 20 % dispersion of proteins in water is not so far from real meat, even if it is lacking many properties of it, and in particular iron inside the heme group, which is important for nutrition (Pizarro, 2016). It is easy to improve the quality of the reproduction by adding various compounds such as lipids, glycogen, lactic acid, minerals, vitamins, etc. (De Castro and Dos Reis, 2013).

In such improvements, the classification of nutrients as macronutrients and micronutrients is helpful. How many compounds should be used to make an artificial meat? The question can be analyzed from many different points of view: nutrition, odor, taste, trigeminal, color...

Each particular aspect can be more or less similar to real meat, but anyway perfect copies do not exist, because it would first need a perfect knowledge of the original system, and even if such knowledge were at hand, the goal of making such copy should be discussed. Also as “meat” is very diverse, with influences of the age of the animals, their diet, the condition of slaughtering, the post mortem treatments, a large variety of different “originals” has to be considered (Przybylski and Hopkins, 2016). In this discussion, one has to take into account that the order of importance, from the composition point of view, has little to do with the order in taste,

odor or color. For a good reproduction, the most important compounds of each aspect of meat have to be considered first.
From where should the compounds come? It is true that chemistry can now synthesize many

Figure 2. A "fibre": this system is formally comparable to meat, from a physical point of view, as it is made from tubes (instead of muscular fibres) full of water and proteins.

food compounds, but one should not forget that an important collaboration was needed for the chemical synthesis of vitamin B12 (a dozen years, hundreds of chemists) (SCF, 2016), and even today a large scale production is hardly possible. Even for simple compounds such as methionine, the chemical production is not a solution today (Jiang *et al.*, 2016), and fractionation and cracking plant tissues would be easier. One has to note that in the future GM plants or micro-organisms could well express particular compounds that would be useful for food diet, but this is prospective (Reynolds and Martirosyan, 2016).
As the physical structure is concerned, other "copies" can be made, one already very popular being "surimi", i.e. fibrous systems made from thermal coagulation of solutions of water and proteins, followed by scraping the sheets produced, and rolling into tubes (Fuller, 2011). Such systems are fibrous, as is meat, even if the fibres are not hollow, and full of water and proteins, among compounds.
Another very simple reproduction of meat can be done with other compounds. For exemple, Figure 2 shows a system that was called "fibre" as early as 2001: it is made of "tubes" (from starch) glued together by proteins, and full of water and proteins, as in meat (Loew, 2016).
Finally, mix of systems can be made, for increasing closeness to meat. This discussion shows that "*in vitro* meat", as grown since 1991 (Levenberg *et al.*, 2005; Post, 2012), are nothing but one kind of artificial meat, and one should ask why it could be useful to grow such tissues, when more simple systems can be made. Indeed the current discussions about meat consumption should not forget to focus on the real interest of meat consumption.

Conclusions and perspectives

The possibility of making various "artificial meats" being established, the issue of food security should be discussed taking into accounts the many questions relative to food, from the production of food ingredients at the farm to nutrition.
First, if compounds can be used instead of whole plants or animal tissues, then agriculture could be in for a change, but so could the food regulation, which would then require some adaptation to allow for dealing with the ingredients adequately, as recently discussed at the European Customs Chemists meeting (CECC, 2013).
Further in the food chain, the questions raised by building food are many, because all sensory aspects of food could be subject to choice: color, taste, smell, consistency, etc. And nutrition also is important, because the new environment of bioactive compounds will be different. In particular, the relevant question is: how should we build NbN food if we had to eat it every day?
The issue of sustainability is obviously important, and different questions are raised depending on whether artificial meat is only a way to replace real meat for some people or if

the humankind is to be fed with such systems. This question is Manichean, and there is no reason to imagine that real food will not be consumed in the future, as certain places such as mountains cannot be used for agriculture. But prospective issues should be discussed from quantitative scenarios. NbNC has to be included among the various possibilities taken into account.

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