International Journal of Food Science and Nutrition
ISSN: 2455-4898
Impact Factor: RJIF 5.14
www.foodsciencejournal.com
Volume 3; Issue 3; May 2018; Page No. 35-40

An overview of the applications molecular gastronomy in food industry

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Abstract
Molecular gastronomy which is a recent development in the field of science has made an immense impact in food appeal and customer satisfaction over the years. Although molecular gastronomy is often mistaken for molecular cooking, molecular gastronomy is the use of advanced chemical and biochemistry to create novel foods. With the introduction of disperse system formalism a number of new recipes in molecular gastronomy are introduced. It is only with the presence of the necessary ingredients such as the hydrocolloids, techniques like spherification/flash freezing, equipment such as the gastrovac, vacuum machines etc. the molecular gastronomy is achieved. This paper reviews the concepts, latest application of molecular gastronomy in various countries.

Keywords: molecular gastronomy, spherification, note by note cuisine, flash freezing

Introduction

Unlike in the past cooking in household and restaurants has turned out to be more scientific with the development of the concept called Molecular gastronomy. In restaurants Molecular Cuisine (molecular cooking) is still developing in the world (This, 2013) [1]. During the 1980's molecular gastronomy emerged as a result of the need to study the phenomena occurring during culinary processes to rationalize the culinary techniques, as science those days was mainly emphasizing on chemical composition of the food ingredients and industrial processes. The founders of Nicholas Kurti and Herve' in 1988 have referred Molecular gastronomy as a scientific discipline or the knowledge of whatever concerns man's nourishment (This and Kurti, 1994) [2]. It is defined as looking for the mechanisms of phenomena occurring during dish preparation and consumption incorporated with artistic and social components (This, 2013; This 2009) [3, 4]. Molecular gastronomy is quite popular and advanced in counties like France, Argentina, Switzerland and Spain. Molecular gastronomy has led to Molecular cooking and note by note cuisine (This, 2013) [1].

Chemical and physical techniques that are applied in some restaurants to produce novel textures and flavor combinations has led to appreciation of food. It can be said that molecular gastronomy debunks some traditional cooking myths as such the aims of molecular gastronomy are to collect and investigate methods of traditional cooking, scrutinizing existing recipes; to introduce new tools, products and methods to cooking; to invent new dishes and to use the appeal of food to promote science. In the other hands, note by note cuisine which is the next culinary trend uses compounds, either pure compounds or mixtures obtained by fractioning plant or animal tissues (Everts, 2012) [5].

The concepts of Molecular gastronomy

The concepts of Molecular Gastronomy are applied to create high-quality foods having high sensory properties and consumer acceptability and satisfaction. The principles of Molecular gastronomy have led to the invention and testing of new methods of preparation, cooking, presentation, and combination of foods such as flash freezing using liquid nitrogen. Some examples of molecular gastronomy foods are a miniature apple, cocktails in ice spheres, caviar made of olive oil, transparent raviolis, spaghetti made from vegetables, instant ice cream, balsamic pearls, honey caviar with gelatin, chocolate, espresso caviar and many others. Molecular Gastronomy scientific program is composed of exploring the technical, artistic, social components of cooking and culinary activities (Caporaso and Formisano, 2015; Barham *et al*., 2010) [6, 7].

Types of colloidal system that is making Molecular Gastronomy work are foam, solid foam, solid gel, emulsion, solid emulsion (Hill, 2009) [8]. Techniques of molecular gastronomy include spherification, flash freezing, meat glue, froth, aromatic component, use of emulsifiers, Whimsical or avant-garde presentation style, different flavor combinations, new food textures (gels, foams, glass like food), cooking in a microwave, high pressure cooking, improved temperature control, high-power mixing and cutting machines for example ultrasonic agitation to create emulsions.

Spherification is when liquidized food such as apple juice is mixed with sodium alginate and then bathed in Calcium Chloride creating multiple spheres (Halford, 2015) [9]. The technique where the calcium chloride ions cause the long-chain alginate polymers to become cross-linked, forming a gel is commonly used in making caviars. Flash freezing is when the exteriors of the food are frozen by liquid nitrogen. Meat glue is transglutaminase that binds different proteins together. Froth is the sauce converted to foam using whipped cream canister. Lecithin acts as a stabilizer (GourmetFoodWorld, 2013) [10].

The ingredients commonly used in molecular gastronomy are gelling agents like methylcellulose, Sugar substitutes, emulsifiers like soy lecithin and xanthan gum, non-stick agents, Enzymes, such as transglutaminase-a protein binder, carbon dioxide, for adding bubbles and making foams, hydrocolloids such as starch, gelatin, pectin and natural gums used as thickening agents, gelling agents such as methylcellulose, xanthan gum, agar, and gellan, each having distinct biophysical properties, emulsifying agents and stabilizers. (Mojca Jez, 2015; Brenner & Sörensen, 2015) [11, 12].

Since 2005, certain dishes on the basis of molecular gastronomy were named after famous chemists or scientists, for example Gibbs is a product obtained by whipping egg white with oil, and then the white emulsion obtained is cooked in a microwave oven. The emulsion is then trapped into a gel, Vauquelin is a chemically jellified foam obtained by cooking the foam from whipped egg by microwave. A coagulated egg prepared without the use of heat is known as a Baume egg after the French chemist Antoine Baume (This, 2006; Michaelides, 2008) [13, 14].

Dispersion system formalism was used to describe the organization of different food stuffs or food space. Eg: simple sauce such as a *béarnaise* consists of three phases: solid matter (microscopic egg-yolk aggregate) and a hydrophobic liquid (oil droplets) dispersed in a hydrophilic liquid (water). In order to describe the microscopic structure of such a system, the ‘complex disperse systems' formalism was proposed in 2002 at the European Colloid and Interface Society Meeting (Vega & Ubbink, 2008) [15]. Now, using the complex disperse systems' formalism, the number of different sauces made is potentially infinite, because new formulas can lead to new dishes.

Applications of Molecular gastronomy

1. Temperature control and sous-vide

Sous vide cooking is defined as “raw materials or raw materials with intermediate foods that are cooked under controlled conditions of temperature and time inside heat-stable vacuumized pouches” (Schellekens, 1996) [16]. Sous vide cooking differs from traditional cooking methods as the raw food is vacuum-sealed in heat-stable, food-grade plastic pouches and the food is cooked using precisely controlled heating (Baldwin, 2012) [17].

Sous vide is cooked under control by applying a certain temperature (65-96º C) / time after vacuuming in the package of the food which is formed alone or with other auxiliary products (sauce-spices) and stored under cold conditions (1-4º C) by rapidly reducing the temperature after heat application. In the products prepared by this technology, the blocking effect provided by oxidative and aerobic bacteria development through vacuum packaging combines with microbial protection effect provided by pasteurization (Yıkmış S *et al.* , 2018) [18].

One of the advantages usually reported for the meat cooking sous-vide is the greater juiciness and higher nutritional value due to more concentrated nutrients. The cooking time was reported to have very little or no influence on the red color of cooked meat at moderate temperatures, even after cooking for a very long time, whereas there was a trend towards a higher redness in meat sous-vide cooked at 60 °C for 12 hours, compared with those packaged with air. (Caporaso and Formisano, 2015) [6].

2. The use of liquid nitrogen

It is particularly useful as a quick-and-easy way to rapidly cool the temperature of food preventing the growth of ice crystals. Big crystals are known to damage frozen foods. Two examples of its application are represented by herbs grinding, where herbs are simply mixed with liquid nitrogen in a mortar and rapidly frozen in brittle solids, and ice cream making. In the first case, oxidation can be avoided; therefore, the color and aroma compounds are preserved. In the second case, nitrogen allows the creation of an “instantaneous” ice cream with a very smooth taste due to the smaller size of the ice crystals. Although liquid nitrogen has no negative impact on consumer’s health, care should be taken during use, particularly for eyes of the operator (chef), but also for the consumer. Ingestion of liquid nitrogen is rare but carries catastrophic complications related to barotrauma to the gastrointestinal tract (Berrizbeitia *et al*., 2010) [19].

3. Applications of ultrasound in food preparations

Among the positive factors of using ultrasonic treatment, there is the use of neither chemicals nor additives, the process is easy and rapid and it does not induce large chemical changes in food. It has been reported an increased muscle protease activity that consequently caused meat colors change. Ultrasound promotes a better size distribution bubbles. The sensory profile was better for the sonicated product. Ultrasound treatment also caused a lowering in the viscosity.

Therefore it has been suggested that ultrasound treatment can lead for the development of off-flavors mainly due to excessive lipid oxidation, and attention should be put to these aspects, but also to the color and viscosity changes. Pohlman *et al*. (1997) [20] stated Ultrasound offers a new cooking mode that could increase cooking speed, improve energy efficiency and improve some textural characteristics, compared to conventional cooking. Ultrasonic can be made use in achieving nano emulsions. Mostly the oil in water emulsions are important vehicles for delivering hydrophobic bioactive components in a range of food products especially in the beverage industry. The use of ultrasound for this purpose can be competitive or even superior in terms of droplet size and energy efficiency when compared to classical rotorstator dispersion (Kentish *et al*., 2008) [21].

4. “Spherification”

Spherification is the shaping of a liquid into small edible spheres in calcium-alginate capsules by applying the techniques of “reverse gelation.” The spheres have liquid center and look like caviar. This is the center for formation of faux caviar, eggs, gnocchi and ravioli (Lee & Rogers, 2012) [22]. Chefs have adopted both direct and reverse spherification. For direct spherification, the water solution containing the food or aroma and a gelling agent, usually sodium alginate, is slowly added to a second bath containing the missing ions, e.g., calcium chloride. When the droplets fall into the bath, the process of gelification starts and small gel capsules with a liquid core or chewy beads are obtained, depending on the dip into the bath. In reverse spherification, calcium lactate, or other source of calcium ions, is added to the edible liquid. The bath contains unset gel, which is made using deionized or distilled water. When the food is added, the bath solution itself forms a skin of gel around it. Calcium acts like a bridge between the alginate chains, enhancing their interactions and favoring gelation (Halford, 2015) [9].

Spherification could be considered in the broad sense as an encapsulation method. The viscosity of the calcium chloride/emulsions and alginate solutions increases with the increase of calcium chloride and alginate concentration. If the viscosity of the emulsion is higher than that of alginate solution, droplets deformation during impact with the alginate solution is smaller at higher degree of emulsion viscosity. Challenges related to spherification include the choice of the correct acidity and calcium concentration, and the most appropriate solution density and concentration of flavoring agents. It has been applied for the formulation of new food products or functional foods or to optimize the sensory aspect through the addition of new aromas and flavors (Caporaso & Formisano, 2015) [6].

Other applications of Molecular gastronomy involves use of maltodextrin with $15 \leq DE \leq 20$ to produce the powdered olive oil by forming tiny capsules of oil which, when placed in an aqueous medium, turned back to its original liquid structure. Maltodextrins consist of beta-D-glucose units linked mainly by glycosidic bonds (1–4) and are usually classified according to their dextrose equivalency (DE). Normally, maltodextrins have a DE value under 20. Maltodextrins with different DE values have different physicochemical properties, including solubility, freezing temperature, viscosity, etc., flavorings and sweeteners (Guine *et al*., 2012) [23].

Another research that employed a molecular gastronomy principle exploring additive manufacturing, specifically extrusion-based layer-wise deposition, can be combined with the reverse spherification technique that is widely used in molecular gastronomy. A desktop extrusion is adapted for the deposition of a calcium solution into an alginate bath first as a two-dimensional (2D) pathway and then as three-dimensional (3D) geometry by layer-wise deposition. We demonstrate that motorized extrusion-based additive manufacturing can be combined with reverse spherification to form stable objects by gelation of fruit-based solutions. This study shows that 3D printing via reverse spherification can bridge the gap between culinary arts and additive manufacturing technology, and enable new capabilities for creation of dining experiences. This is a step toward the digital design and manufacturing of unique edible objects with complex flavors, textures, and geometries (D'Angelo *et al*., 2016) [24]. Horvath (2014) [25] explains the use of the fruit 3 D printer to make thin skinned fruit juice droplets using spherification technique.

Brenner, M. and Sörensen in 2015 [12] suggest three noteworthy ways of producing small flavor molecules (extract, isolate), capturing and concentrating aromatic molecules, creating flavor molecules through chemical reactions such as maillard and caramalization reaction, and finally through food fermentation, an example known to be is unconventional combinations of foods and microbes to create new recipes, such as pomegranate seeds with lactic acid bacteria, commonly used in dairy fermentations.

Also, there are ongoing researches that suggest food engineering becoming integrated with gastronomy's concerns about safety, sustainability and nutrition (Aguilera, 2018) [26].

Molecular gastronomy in different countries across the world

The recent developments of Molecular gastronomy in some countries have been reviewed by a number of papers published over the last few years. In particular, there is information regarding molecular gastronomy in France, Ireland, Lebanon, UK, Denmark, and Spain. Some of the popular restaurants for molecular gastronomy are Alinea restaurant in Chicago, wd~50 restaurant in New York, Restaurant Chateau Cordeillan-Bages in Bordeaux, France, Ozu restaurant in Paris (Hill, 2009) [8].

The English chef Heston Blumenthal introduced food process innovations in restaurant cooking such as "sous-vide," as well as the "bacon and eggs ice cream". Other famous chefs are e.g., Homaro Cantu, for the use of lasers in the kitchen; Grant Achatz, who invented new ways to present dishes and innovations such as the spray-dried instant puddings; Pierre Gagnaire, who replaced the conventions of classic French cooking by introducing jarring juxtapositions of flavors, tastes, textures, and ingredients; Massimo Bottura, an Italian chef who "reinvented" the tradition by using food ingredients in innovative ways, etc.

Following the success of UK chefs Heston Blumenthal and Sat Bains, the application of science to cooking is becoming increasingly popular in the UK. Initially, this started in the big food science centers of UK universities, but now science is becoming embedded in catering courses, and evening lectures on science-related food topics are increasingly popular. This trend is being taken up by restaurants and even bars around the UK, as scientific books, equipment, and ingredients are starting to crop up in food and drink destinations around the country (Edwards-Stuart, 2012) [27].

In France, even before Molecular gastronomy was created a lot of activities have been organized, in particular around the MG Group, formerly at the Collège de France and at Agro Paris Tech since 2006. For schools, educational curriculum called flavour experimental workshops were introduced in 2001 (This, 2011) [28].

Spain had been recognized as the first country in which additives such as sodium alginate, gellan gum of glycerol monostearate, etc., were massively commercialized for restaurants and foodies. In addition, Spain had been one of the main producers of new professional kitchen appliances based on equipment from research labs such as the Gastrovac, the Rotaval or the Roner and was one of the few countries in which many of the main researchers involved in these topics had been linked through a collaborative network called INDAGA: Research, innovation, and development applied to gastronomy (García-Segovia, 2014) [29].

Molecular gastronomy was first introduced in Lebanon in 2011 through a series of conferences addressed to various audiences. Since then, actions followed to assure the perpetuity of this initiative and aim for the creation of a Lebanese group of molecular gastronomy, gathering people from different backgrounds (academia, food industries, and culinary chefs) (Barbar & This, 2012) [30].

Molecular gastronomy in Sri Lanka is still at the budding level. Dilmah being one of the leading tea producers and exporters of Ceylon tea has begun its exploration of ‘tea gastronomy’ in 1999 with roast chicken marinated in Ceylon Tea. Later they have come up with tea cocktails, Rose with French Vanilla Tea Sherbert with Rosehip and Hibiscus Tea Foam, Chilled Ripe Tomato, Blueberry & Pomegranate Tea Water with Alaskan Crab Stick, "Vanilla Ceylon Tea" Ice Cream etc. (Pressroom-dilmahtea, 2017) [31].

The role of equipment in the new culinary art science of molecular gastronomy is as vitally important as that of the ingredients themselves. In fact, to attempt many of the techniques without the correct equipment is fraught with danger and destined for disaster. The cost and availability of the equipment is also a factor in whether or not an establishment can and will commit to this modern service style.

Table 1: Equipment used in Molecular gastronomy (Source: Hill, 2009) [8].

Equipment	Description
Standard Digital Circulator	Cook foods at very low temperatures in liquids The food is generally placed in bags and vacuumed sealed sous vide style. The pump circulates the heated liquid to maintain the right temperature.
Induction Cook-tops	Induction cook-tops are extremely powerful. use much less energy than conventional cook-tops
Excalibur Food Dehydrators	Different preparations are dried and then some are served cold. Some warm directly from the dehydrator and others are dried first and then baked or even deep fried to produce crisp wafers from fruits and vegetables.
Pacojet High Speed Processor	It is particularly effective in creating heavenly ice creams and sorbets. The flavoured mixture is placed in the canisters, frozen and then placed on the Pacojet and blitzed to form the smoothest, lightest iced desserts. Preparing savoury items, mousselines and pastes.
Vitmix Vita-Prep Blender	Disperse powdered gums and thickeners into liquids, greatly reducing the time and the problems normally associated with this process, such as lumps, incomplete dissolving, and a particle size that is too course.
Thermomix	The Thermomix has an amazing ability to chop, beat, mix, whip, grind, knead, mince, grate, juice, blend, heat, stir, steam and weigh food. It is ideal for complex recipes where colloids have to be carefully mixed and heated.
Vacuum Machines	Uses of vacuum machines for general storage; but more importantly, for sous vide cooking in conjunction with a Circulator. Food items can also be placed in a bag, with marinades, dressings, sauces, seasonings or wines added and vacuumed, to facilitate the flavour penetrating into the menu item. The percentage of air removed can be selected and in some cases gas (CO_2) can be flushed into the bags and sealed to provide additional shelf life and food safety. Used in Sous vide cooking.
Smoke Machines	Used to pump smoke into serving vessels, or bags to perfume foods with smoke. A multitude of different effects can be produced by using different commodities to produce the smoke. It is also a stunning presentation to serve food under a smoke-filled cloche and lift it at the table, so that the diner gets the fragrance as an additional sensation.
Thermo Whip	It can keep contents cold for up to eight hours, without refrigeration, it can keep ingredients hot, without the need to reheat, for up to three hours. Perfect for creating and storing delicate soups, sauces, gravies, whipped items and of course excellent for modern foams, spumes and airs.
Soda Chargers	Soda chargers contain eight grams of CO_2 (carbon dioxide); one charger is used per bottle fill. They are leak proof and have no expiration date. Generally made of 100% recyclable steel, coated with a water-soluble lacquer.
Gastrovac	The Gastrovac is a compact appliance for cooking and impregnating in a vacuum. It functions by creating an artificial low pressure, oxygen-free atmosphere, and considerably reduces cooking and frying temperatures, maintaining the texture, colour and nutrients of the food. Moreover, the Gastrovac creates the ‘sponge effect’. When the atmospheric pressure is restored, the food absorbs the liquid around it, allowing infinite combinations of foods and flavours.
Nitral	A Tool to Cook with Nitrogen Consists of a container. It is especially recommended for preparations using liquids at very low temperatures, such as nitrogen. Nitral is 100% stainless steel to prevent cracking. Its inner coating is made of rubber and Teflon to minimise liquid evaporation and temperature transfer.
Green Star Juicer	Regarded as the most versatile juicer on the market, it can turn almost all fruit and vegetables into juice or liquid quite effortlessly. It is also an excellent tool for making almond or date flours, walnut or vegetable pastes, and sauces made with different combinations and of all kinds. As well as its great blending capacity, it has the efficiency of its patented magnet system that creates a magnetic field resulting in the concentration of minerals being increased and oxidation reduced, so that the juices and liquids maintain their nutritional values, and do not lose a lot of flavour.
Superbags	The Superbag is a revolutionary bag. It is a porous filter manufactured in an inert, flexible and heat-resistant material suitable for cooking, and it adapts perfectly to different containers. The Superbag is ideal for preparing consommés, making stocks and, in general, cooking large quantities of ingredients. During these processes it reduces the amount of water the cook needs to use and saves a great deal of time.
Caviar Spherification Tool Kit	These syringes are used to evenly deposit the flavoured liquid into a calcium or alginate bath to form tiny spheres, generally called ‘caviar’, for use in garnishing dishes. Larger spheres, up to the size of egg yolks can be achieved by using demi-sphere spoons to portion the mixture.
Ruby Jewelry Scale	The ingredients, gums and colloids must be measured exactly for each recipe to obtain best results. Even minute quantities or errors can have a significant effect on the final dish. These tiny but highly accurate scales are invaluable when weighing up components for various recipes (Ivanovic, 2011).

Analytical methods for molecular gastronomy

The culinary transformations induce physical modifications of the microstructure of the dish as well as changes in the chemical contents of the various compartments that make up the dish so chemical and physical analytical methods are needed. Analytical methods such as Ultraviolet, Infrared and mass spectroscopy can also be used to achieve more detailed description of changes.

In order to investigate the microstructural modifications (which determine the bioactivities of the food molecules), it is important to consider that most dish components are colloidal systems, so analytical methods for studying such physical systems are needed. Of course, when possible, methods that provide information directly (without sample preparation) should be used, such as neutron beams, X-rays, but also confocal microscopy/image analysis or nuclear magnetic resonance imaging.

As culinary transformations are dynamic processes, obtaining the evolution of the formulae over time is the objective. In practice, complex gels are found to be at the heart of the activity, because plant and animal tissues are formally gels, with a liquid phase dispersed in a solid, continuous phase. Other analytical methods, such as NMR, various microscopies (optical, fluorescence, UV, IR, confocal, etc.), as well as various separation (EC, HPLC, GC-MS…) and identification (mass spectrometry) methods can be used to achieve more detailed descriptions of changes. Since dish components are complex systems, fast analytical methods are needed for chemical analyses. When possible, of course, sample modification should be minimized, as in other fields associated with metabolomics. Interpreting such analyses, which involve a large amount of data, requires the use of chemometric methods (This & Rutledge, 2009) [32].

Conclusion

Molecular gastronomy is the mechanisms of phenomena occurring during dish preparation and consumption. The physical and chemical changed are produced as a result of various techniques and methods. The bio physical changed can be studied through different analytical techniques.

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