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Science and Technology for New Culinary Techniques

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The use of new culinary tools, methods, and ingredients in the kitchen of renowned restaurants has become common worldwide. Most of these novelties have been based in equipment, ingredients, and procedures from the food industry and food labs. There are four main topics in which this cooperation between the science and the culinary fields takes place: (a) the use of scientific knowledge about perceptions; (b) taking advantage of the scientific knowledge about food composition and properties; (c) the use of nontraditional ingredients and knowledge concerning their application to culinary uses; (d) the usage of industrial and scientific technologies that are far from traditional culinary technologies. The contribution of scientific information for the evaluation of safety issues is also of great importance for these new culinary developments, because in some cases, there is a lack of normative and basic food safety working procedures. This review deals with different aspects of some of these new tools, procedures, and ingredients, including basic scientific background, technological questions, and food safety concerns.

KEYWORDS Cooking, sous-vide, transglutaminase, rotary-evaporator, senses

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INTRODUCTION

Culinary techniques have been empirically developed for ages. In fact, until the 1990s, scientific knowledge about food and industrial technology hardly applied to culinary methods utilized at home or in restaurants. However, during the last decade, there has been a growing interest in acquiring a deeper knowledge about the chemical and physical changes that take place during culinary preparations used in top restaurants (This, 2005). In addition, chefs' interests have turned toward the use of additives and technologies commonly utilized in the food industry. Thus, the most renowned chefs (Ferran Adria, Heston Blumenthal, Pierre Gagnaire, and so on) and most fashionable restaurants all over the world have developed culinary methods based on the use of these "new" ingredients and processes. As a consequence, more chefs have adopted and/or imitated these culinary innovations in their kitchens, and in the last few years, the catering and ready-to-eat food industry have also embraced some of these culinary techniques for their products.

The ways in which science may help the culinary world can be summarized in four main fields: (a) development of new recipes by using scientific knowledge concerning human perceptions of food characteristics (i.e., how bitter taste is minimized with small amounts of sodium chloride in the food); (b) optimization of cooking procedures and development of new cooking settings by taking advantage of the scientific knowledge about the composition and properties of different foodstuffs (i.e., the control of cooking temperatures to obtain a range of boiled egg textures; Vega & Mercadé-Prieto, 2011); (c) use of nontraditional ingredients and knowledge about their use for developing new culinary applications, sometimes far from those for which they were initially developed (i.e., the use of sodium alginates for making false caviar of different juices); (d) culinary use of technological and scientific tools that are not traditionally found in kitchens (i.e., the use of lab equipment, such as a temperature-controlled water bath, for sous-vide cooking).

However, scientific knowledge behind the culinary use of some of these tools still is limited, because some of their uses in the food industry are not the same as those for which they were developed. Moreover, some of these new ways of preparing different dishes could show adverse consequences for consumers and have not been entirely evaluated and scientifically considered.

This review briefly explains some of these scientific and technological tools used by renowned chefs, such as vacuum cooking at controlled temperatures, the application of transglutaminase (TGase) for culinary preparations, and the use of rotary evaporators for culinary purposes considering their applications to culinary processes. The importance of scientific knowledge in the culinary field will also be highlighted by evidencing its role in assuring the safety of some new culinary technologies.

Scientific Knowledge About Human Perception: The Case of Senses Habituation

Our senses tend to adapt to stimuli in the environment in order to avoid fatigue or process redundant data. For example, if one moved close to a church, on the first day, one would hear the bells toll at all hours; a few months later, one would hear the bells only if he or she was paying attention. A similar process takes place when eating: the first bites are truly enjoyed, but after a while, the odor and taste senses adapt and the food is not as exciting. In fact, it has been demonstrated that the perception of a certain flavor decreases over time even though the concentration of such flavor compound remains unchanged within the nose (Davidson, Linforth, Hollowood, & Taylor, 1999).

As Barham et al. (2010) have reported, there are different ways to take advantage of this phenomenon. For example, eating small dishes with different textures and flavors (for example, tapas in Spain, or the tasting menu at many top-level restaurants) will be more pleasing than eating the same amount of food of a single dish. There are also examples of dishes created to make the most out of this effect: recipes created around a single ingredient (i.e., an apple) but varying the textures (a mousse, an ice cream, raw slices, dehydrated slices, a gel). Perhaps the most original of this type is the cauliflower risotto created by Heston Blumenthal, in which the main ingredient is cauliflower but in a variety of textures (dried, raw, a foam, a cream) and with some flavor contrasts (cocoa jelly cubes; Figure 1). The guest constantly perceives changes in texture that make the senses continuously aware of what is being eaten and, thus, habituation of the flavor is avoided.

Scientific Knowledge About Food Composition and Properties: The Case of Low-Temperature–Long-Time Sous-Vide Cooking

Sous-vide cooking can be defined as the cooking of raw materials or raw materials with intermediate foods under controlled conditions of temperature and time inside heat-stable vacuum pouches or containers (Schellekens, 1996). After heating, the products are rapidly cooled to temperatures of around 0–3°C. This technique was originally developed for the catering industry, allowing the manipulation of the prepared food after thermal treatment with no risk of contamination (Schellekens, 1996). The use of sous-vide cooking has greatly spread in top restaurants because it allows easy and safe handling of the already cooked dishes at the restaurant. A commercial appliance, the Gastrovac (ICC, Barcelona, Spain), is available for cooking unpackaged food under continuous vacuum. This cooking procedure was called cook-vide by the authors of this patented equipment (Martínez-Monzo, Andrés, Torres, San Juán, & García-Segovia, 2004).

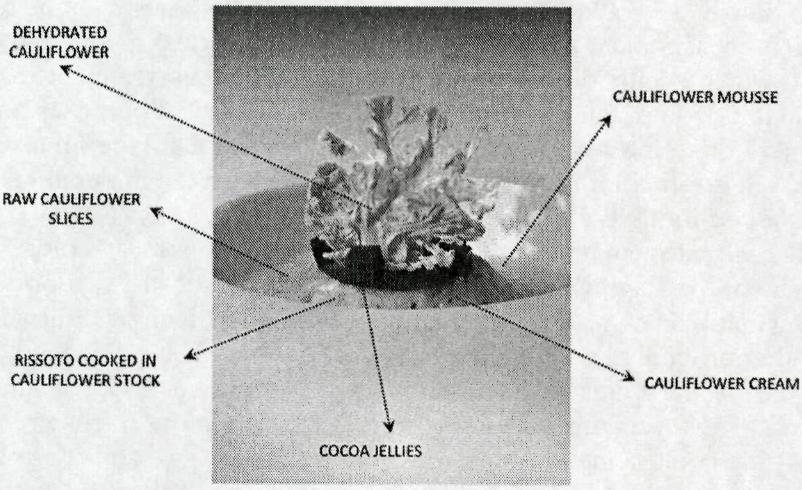

FIGURE 1 Cauliflower risotto by Heston Blumenthal (The Fat Duck restaurant, UK). A recipe designed to avoid the habituation of human senses by including different textures and flavors (picture taken from http://www.dominicdavies.com/) (color figure available online).

However, compared to the conditions for sous-vide cooking used in the catering industry, chefs cook meats at considerably lower temperatures and much longer times (Myhrvold, Young, & Bilet, 2011). Why? Most of the desirable effects achieved by using these combinations are due to the effects of temperature on muscle proteins. Increasing temperatures cause denaturation and shrinkage of myofibrillar proteins in the temperature range 40–90°C (Tornberg, 2005) and shrinkage of collagen in the temperature range 56–62°C (Larick & Turner, 1992; Tornberg, 2005). Up to 60°C, the muscle fibers shrink transversely and the gap between fibers widens, but above this temperature the muscle fibers shrink longitudinally and cause substantial water loss; the extent of this contraction increases with temperature. The amount of water lost during cooking increases with temperature, especially above 70°C. Thus, a very important effect achieved by controlling temperature is a higher holding of meat juices during cooking, which in turn leads to juicier meat. Therefore, a good understanding of protein shrinkage as a consequence of heat allows chefs to obtain more tender and juicier cooked meat.

Meat's color is mainly caused by a sarcoplasmic heme protein called *myoglobin*. Under a normal atmosphere, the myoglobin in fresh meat tends to bind to oxygen molecules; this is called *oxymyoglobin* and shows a bright red color. Upon heating, myoglobin firstly tends to oxidize, giving rise to metmyoglobin, which shows a brownish color. Further heating will denature myoglobin, producing a brown pigment called *globin myohemichromogen*. Such processes take place between 55 and 65°C and continue up to 75 or

80°C (King & Whyte, 2006). Meat cooked under low-temperature–long-time (LT-LT) sous-vide cooking conditions, below 65°C, shows a more reddish color than meat cooked by traditional methods, due to less myoglobin denaturation, which occurs despite the length of the cooking treatment (Sánchez del Pulgar, Gázquez, & Ruiz-Carrascal, 2012). For practical purposes, this fact may prove quite interesting; chefs value the fact that cooking time will not affect the reddish color of the meat cooked at moderate temperatures, even when cooked for a very long time.

There is also an effect of sous-vide cooking on meat color due to the vacuum packaging: vacuum packaging increases the proportion of deoxymyoglobin in fresh meat; such a redox state of myoglobin shows a higher thermostability compared to oxy- and metmyoglobin (Mancini, 2009), which means that a greater proportion of myoglobin remains intact after heat treatment. Thus, vacuum packaging contributes to a more intense red color of sous-vide cooked meat.

Changes in meat tenderness during cooking are associated with heat-induced alteration of myofibrillar proteins and connective tissue, because heat above 60–62°C solubilizes the connective tissue, and this leads to meat tenderization (Figure 2); conversely, denaturation of myofibrillar proteins causes meat toughening, which starts below 60°C but becomes more intense

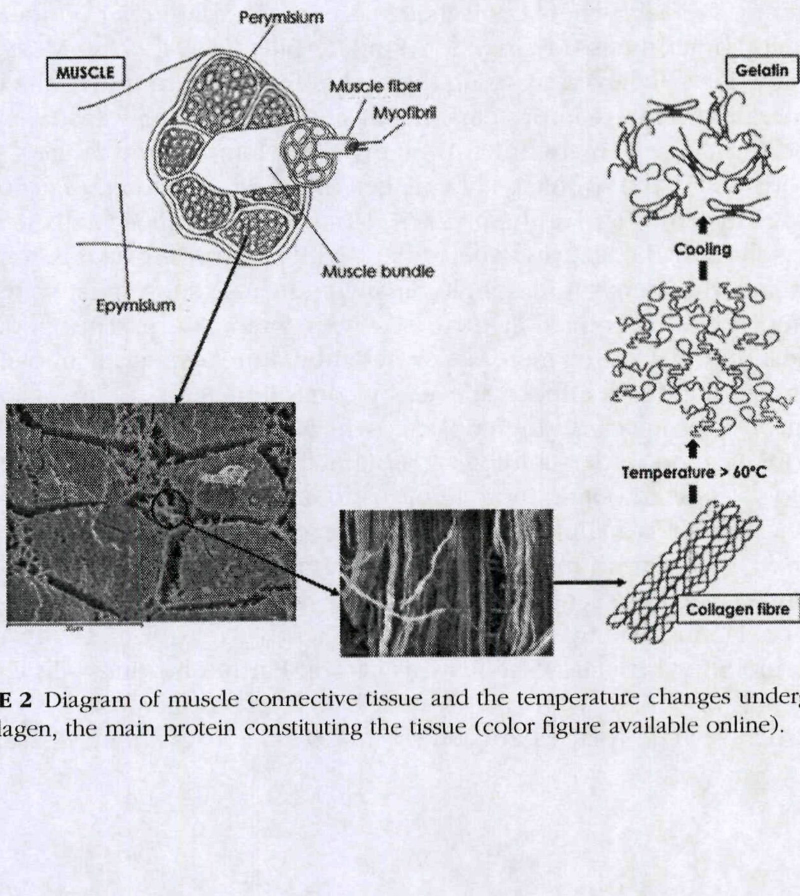

FIGURE 2 Diagram of muscle connective tissue and the temperature changes undergone by the collagen, the main protein constituting the tissue (color figure available online).

above 70°C (Laakkonen, Wellington, & Sherbon, 1970; Tornberg, 2005). Water losses from the muscle tissue upon heating also contribute to meat toughening. In addition, the change from a viscoelastic to an elastic material influences the changes in texture during heating (Baldwin, 2012): raw meat is tougher because of the viscous flow in the fluid-filled channels between the fibers and fiber bundles; heating up to 65°C increases tenderness because the sarcoplasmic proteins aggregate, forming a gel, which makes it easier to chew; over 65°C and up to 80°C, the meat becomes tougher because the elastic modulus increases and requires higher tensile stresses to extend fractures (Tornberg, 2005). Moreover, Laakkonen, Sherbon, and Wellington (1970) detected a residual collagenolytic activity at 60°C after 6 hours, compared to that of raw meat or meat cooked at 37°C for 6 hours. Baldwin (2012) suggested that this residual collagenase activity at 60°C could explain the tenderness of meat cooked at such temperatures for long times. However, in the same work by Laakkonen, Sherbon, and Wellington (1970), the activity for the muscle collagenase at 60°C was around four times lower than that at 37°C. If such collagenolytic activity at 60°C were real, then keeping the meat at 37°C for a shorter time would achieve a similar effect.

Thus, overall, heating at a temperature between 58 and 65°C will produce collagen solubilization and subsequent gelatin formation that will contribute to the tenderness of cooked meat. On the other hand, myofibrillar shrinkage due to temperature will lead to a tougher structure. This process is temperature dependent, starting at around 55°C but increasing dramatically above 65–70°C. This means that there is a range between 58 and 65–67°C where the temperature is high enough for collagen solubilization but still low enough for massive myofibrillar shrinkage. At these temperatures, the longer the cooking time, the greater the collagen solubilization, and thus, if the cut of meat has a lot of connective tissue, it will require long cooking times, whereas this is not the case for tender cuts.

Results for LT-LT sous-vide cooking of pork (Díaz, Nieto, Garrido, & Bañón, 2008; Sanchez del Pulgar et al., 2012), beef (Garcia-Segovia, Andrés-Bello, & Martínez-Monzo, 2007), and lamb (Roldán, Antequera, Martín, Mayoral, & Ruiz, 2013) have confirmed the effect empirically observed by chefs regarding juice retention, texture, and color.

Scientific Knowledge About Nonconventional Culinary Ingredients: The Case of TGase

Food additives are perceived by many consumers as a health risk (Haukenes, 2004), though reports of poisoning due to food additives are rare and there is little scientific information on safety concerns regarding their use at allowed levels. Similarly, most chefs have traditionally been reluctant to use them as functional ingredients in their recipes, with the exception of, for example, monosodium glutamate in Asian cuisines. However, in the last few years the use of some food additives has become popular in top and medium-level restaurants, and a few companies have commercialized pure additives and blends for cooking purposes (i.e., Texturas el Bulli in Spain, Cuisine Innovation in France, and Le Sanctuarie in the United States). Stabilizers, gelling agents, and/or thickeners hydrocolloids are probably the most popular additives in culinary applications, especially sodium alginate, xanthan gum, gellan gum, carrageen or methylcellulose, although emulsifiers such as lecithin, monoglycerides, or sucrose esters of fatty acids have also become very fashionable for producing aerated foams. Although most food enzymes are not strictly considered additives by the European Union legislation, they will be soon incorporated to a unified list of food additives, food enzymes, and food flavorings.

TGase is an enzyme (protein-glutamine γ-glutamyltransferase; EC 2.3.2.13) that catalyzes an acyl-transfer reaction between the γ-carboxyamide group of peptide-bound glutamine residues and a variety of amino acids (Motoki & Seguro, 1998). TGase is used in the industry as a glue to keep different proteinaceous ingredients together, allowing the formation of restructured products at room or refrigeration temperatures (Kolle & Savell, 2004) and improving the stability and water-holding capacity of protein-based emulsions (Ruiz-Carrascal & Regenstein, 2002). Some chefs have used these properties to create innovative culinary preparations. For example, Willie Dufresne, the chef of the restaurant WD-50 (New York), has created a dish in which crabmeat and TGase are used to make noodles. In the blog Ideas in Food, chefs Aki Kamozawa and H. Alexander Talbot (2007) have proposed the use of TGase to produce ricotta cheese gnocchis or mozzarella noodles.

TGase has been also used to modify the physical properties of gelatin. The textural properties of gelatin gels and foams are highly valued by chefs; however, such gels and foams cannot be used in culinary preparations that should be served hot, because gelatin melts between 30 and 40°C. By enzymatically modifying gelatin with TGase, gels and foams made with gelatin can be made thermostable (Figure 3), allowing them to be heated. We have evidenced that foams and gels made with gelatin treated with TGase are stable at 80°C for a considerable time (Ruiz, Antequera & Calvarro, 2007; Ruiz, Galiano, & Calvarro, 2007), although the textural properties of such gels are modified and should be optimized (Ruiz & Calvarro, 2007).

With regard to concerns about the use of TGase in culinary preparations, the intrinsic presence of TGase in vegetal and animal foodstuffs that have been consumed for ages (Motoki & Seguro, 1988) shows that its consumption is likely not involved in toxic processes. However, the enzyme used in food applications has a microbial origin and could show a different activity. Nevertheless, in the few studies in which such toxicity has been evaluated, neither acute nor long-term toxicological effects have been detected (Bernard, Tsubuku, & Shioya, 1998).

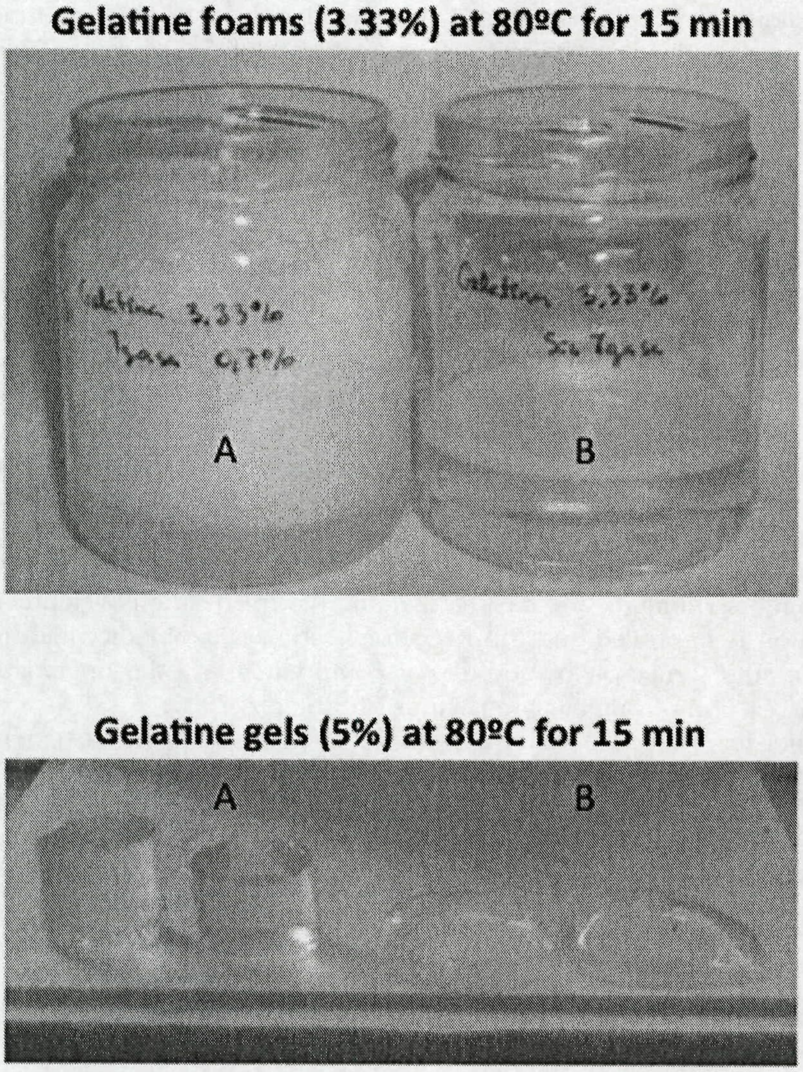

FIGURE 3 Foams and gels made with gelatin. The "A" samples were incubated with microbial TGase (30 units/g protein) overnight, prior to heating in the oven (80°C for 15 min); the B samples did not contain TGase. Taken from *Improvement of the Thermal Stability of Commercial Porcine Gelatine Gels by Enzymatic Modification With Microbial Transglutaminase*, by J. Ruiz, C. J. Galiano, and J. Calvarro, 2007, presented at Euro Food Chem, Paris, France, August (color figure available online).

Scientific Knowledge About Nonconventional Culinary Techniques: The Case of the Rotary Evaporator

Aromatic extracts have been used as flavorings by chefs for ages. The most common way of preparing this type of extract is by infusing an aromatic component (usually plants, but also charcoal, wood, and so on) into an edible liquid (typically oil or water but also vinegar or wine) for a time long enough to enable aromatic and taste molecules to diffuse from the solid into the liquid that will be then be used as the flavoring agent. However, this procedure shows some disadvantages: (a) only some volatile compounds are extracted; (b) the concentration of aromatic compounds depends on the infused ingredient and the infusion solution, but it is usually low; (c) in addition to volatile compounds, pigments are extracted (which will dye the extract), and, in some cases, toxic compounds (for example, polycyclic aromatic hydrocarbons when infusing charcoal or burned wood in oil); (d) nonedible ingredients are not adequate to produce extracts.

In recent years, a few chefs have prepared aromatic extracts through distillation using a rotary evaporator, a very common lab equipment used for solvent evaporation, and a commercial rotary evaporator, known as Rotaval (ICC, Barcelona, Spain), which has been adapted for kitchen use. Compared to the normal distillation process, in which the volatile compounds are extracted from the matrix by heating a flask containing the products aimed to be distilled, in the rotary evaporator, due to the use of reduced pressure and to the spinning of the flask containing the fresh sample (Figure 4), the extraction is improved and the need for heating is avoided, which in turn prevents the formation of new flavor compounds and the degradation or further reaction of original compounds (Rodríguez, 2006).

Chef Joan Roca (El Celler del can Roca, Gerona, Spain) has extensively used this technique, developing recipes such as the "oyster with moist forest soil distillate," in which a nonedible product (moist soil from a forest) is distilled and used as a flavoring in a seafood dish. Or the recipe known as "chromotherapy in white," a dessert made of different components, all of them white but with different textures (gel, foam, sauce) and flavors, because each one is made from different distilled components (cocoa, citrus fruits, coffee, cinnamon, and passion fruit).

Though distilling edible foodstuffs does not constitute a health risk, distilling nonedible materials should be always done with extreme care. First, toxic compounds in the distilled material could be volatile at the pressures used for distillation. Such compounds would be distilled with the rest of the flavor volatiles and thus would be included in the culinary preparation. In addition, the distillation process may generate an aerosol of small liquid drops that are carried with the steam generated due to the combination of low pressure and moderate temperatures. Microorganisms can therefore be transferred from the distilled material to the flavoring extract, which poses a potential harm to consumers. The last version of the Rotaval includes a filter to avoid the passage of microorganisms into the extracts.

The rotary evaporator also allows the production of concentrated solutions from liquids, such as wine reductions or concentrated stocks. Compared to traditional concentration techniques such as heating wine in order to evaporate the ethanol and most of the water, concentration using a rotary

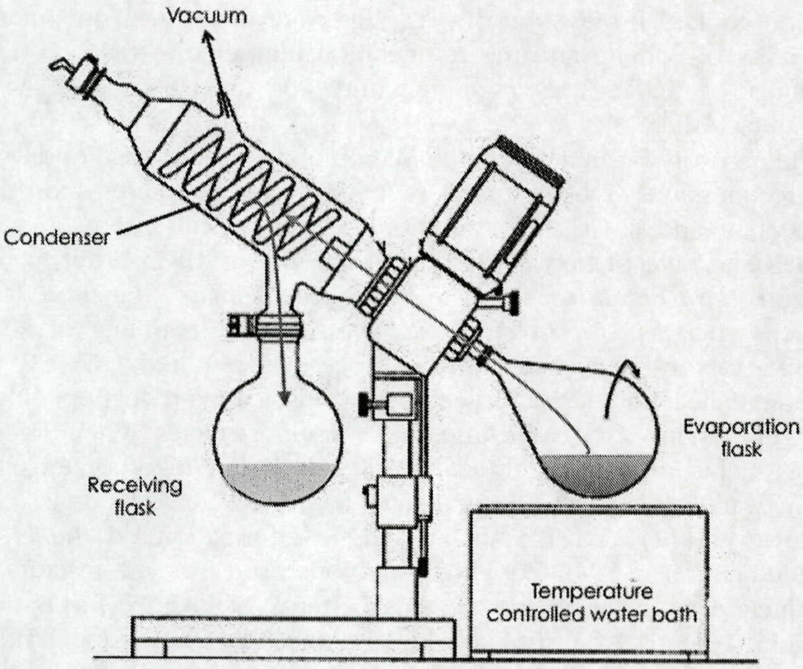

FIGURE 4 Scheme of a rotary evaporator. The product to be distilled is placed in the evaporation flask, whose spin can be controlled. Immersing the flask in the water bath controls the temperature. The whole system is subjected to a vacuum. This, together with the temperature, enables the evaporation of water, ethanol, and volatile compounds. All these are condensed in the condenser, which is cooled with a refrigeration fluid. Condensed compounds are collected in the receiving flask, which will contain most of the flavor volatile compounds of the distilled product. The nonvolatile compounds remaining in the evaporation flask after distillation will be highly concentrated (color figure available online).

evaporator allows smaller losses of aromatic volatile compounds and avoids the formation of new thermally originated artefacts, due to Maillard reactions, thermal degradation of compounds, or thermal oxidation of lipids or other chemical reactions enhanced by high temperatures, because the concentration can be carried out at ambient temperature.

Scientific Knowledge and Safety Issues

Science not only supports creativity in haute cuisine but is the base for enabling the production of safe culinary preparations, which is especially important when using new technologies and ingredients. Two good examples of this are the use of low temperatures in sous-vide cooking and the infusion of charcoal in oils to obtain smoke-flavored oils.

Due to the low temperatures used for sous-vide cooking of fish and meats in some restaurants, there is concern about potential microbiological risks. The three main factors that determine the microbiological safety of sous-vide cooked products are (a) the intensity of the heat treatment, (b) the rapidity of cooling and the refrigeration temperature reached, and (c) the control of chilled storage (temperature and time; Sous Vide Advisory Committee, 1991).

The Advisory Committee on the Microbiological Safety of Food (ACMSF, 1992) recommends a heat treatment of 90°C for 10 minutes or equivalent lethality and strict chill conditions for cook–chill products with an extended shelf life of between 10 and 42 days (<3°C) in order to control the *Clostridium botulinum* risk. In order to eliminate non-spore-forming pathogens such as *Listeria monocytogenes*, a heat treatment of 70°C for 2 minutes or an equivalent heating process is required (ACMSF, 1992). An adequate heat treatment must achieve at least a 6-log reduction in the psychrotrophic strains of *C. botulinum* and *L. monocytogenes*. When less severe heat treatments are used, additional hurdles should be incorporated, such as substances to reduce pH or water activity (Aran, 2001; Genigeorgis, 1993).

However, there is not much scientific information on the effect of the aforementioned LT-LT cooking conditions used in some restaurants on the reduction of these microorganisms. Whereas vegetative forms of most pathogenic bacteria are most likely killed at these LT-LT cooking conditions, and should not be a risk, heat-resistant species, such as *Bacillus cereus* or *C. botulinum*, should be carefully considered. For example, in a recent challenge we carried out on sous-vide cooked lamb, the *D* value for *B. cereus* at 80°C was around 300 minutes (Martín, 2012). Given that there is a chance for some pathogenic bacteria to survive after sous-vide cooking under LT-LT conditions, a great effort should be made by scientists, professors, and publishers to make chefs aware of the critical importance of cooling sous-vide cooked dishes as fast as possible and to keep them below 3°C until consumption in order to avoid growth of bacteria that could have survived the heat treatment.

The infusion of charcoal or deeply burned wood pieces in oil to obtain smoke-flavored oil, which is used for seasoning different dishes, has become very popular. Wood burning produces a variety of chemical compounds, including carbonyls, furans, lactones, acids, phenols (which are mainly responsible for the smoky flavor), and so on. However, polycyclic aromatic hydrocarbons are formed when wood or any other organic material is burned (Maga, 1988). These compounds are well-known carcinogenic, mutagenic, and teratogenic agents, which have been linked to a number of diseases, such as different types of cancer (Fatoki, Ximba, & Opeolu, 2011). The amount of these compounds in the smoke may range from low to considerably high depending on many factors, but the amount in the burned wood or charcoal is tremendous (Fernandes & Brooks, 2003). These compounds show a very low polarity and thus are very well solvated in nonpolar solvents. When infusing burned wood or charcoal in oil, these compounds are selectively solubilized in the oil, because the latter acts as a nonpolar solvent. Therefore, there is a high risk of producing an enriched polycyclic aromatic hydrocarbon oil, which is a safety risk for consumers.

CONCLUSIONS

The application of scientific and technological knowledge in culinary recipes by top-level chefs enables the preparation of astonishing recipes with a range of new aspects, textures, and flavors. This new field of knowledge concerning the cooperation between cooking and science and technology includes the design and development of new kitchen appliances, based on industrial equipment, and the use of ingredients and additives that were not conventional in restaurant use until 10 years ago. However, some of these methods should be studied in more detail and in specific recipes in order to avoid potential harmful effects on the consumer derived from inappropriate use of these techniques. Thus, there is a need for scientific research and development in the culinary field, for innovation in new culinary techniques, for optimization of traditional cooking procedures, and to assure the safety of traditional and innovative recipes. Future research will probably include topics such as the use of some of these novel techniques for developing tasty recipes available for people with food-related diseases, such as celiac disease, diabetes, and phenylketonuria; the specific effect of LT-LT cooking treatments on heat-resistant pathogenic bacteria; and the use of food enzymes for culinary purposes.

In Spain, the network Innovation, Research and Development in Gastronomy has tried to coordinate efforts in this field including different research groups, cooking schools, and companies in the culinary field, organizing events, courses, meetings and participating jointly in publications and projects.

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