Journal of Culinary Science & Technology

ISSN: 1542-8052 (Print) 1542-8044 (Online) Journal homepage: http://www.tandfonline.com/loi/wcsc20

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To cite this article: Betina Piqueras-Fiszman , Paula Varela & Susana Fiszman (2013) How Does the Science of Physical and Sensory Properties Contribute to Gastronomy and Culinary Art?, Journal of Culinary Science & Technology, 11:1, 96-109, DOI: 10.1080/15428052.2012.728983

To link to this article: http://dx.doi.org/10.1080/15428052.2012.728983

Published online: 19 Feb 2013.

Journal of Culinary Science & Technology, 11:96–109, 2013

ISSN: 1542-8052 print/1542-8044 online
DOI: 10.1080/15428052.2012.728983

How Does the Science of Physical and Sensory Properties Contribute to Gastronomy and Culinary Art?

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What occurs in a physical properties and sensory research laboratory is relevant to food developers, chefs, and others working in the hospitality/culinary sector as well as to any curious food lover. Thanks to the contributions of science, the latest food innovations are percolating through to the dining rooms of restaurant managers who want to improve the consumption experience. However, scientific developments and findings are not limited to the food revolution itself. New methods are being applied to understand consumers better and convey correct messages successfully. Contextual factors are also being taken into account when studying consumer perceptions. Taken together, if managed appropriately in a restaurant setting, these insights can enhance the gastronomic experience.

KEYWORDS Physical properties, sensory properties, context, non-sensory factors, food choice, molecular gastronomy, food technology

Received 10 May 2012; accepted 10 August 2012.

The authors are grateful to the Spanish Ministry of Science and Innovation for financial support (AGL2009-12785-C02-01) for the contract awarded to the author Paula Varela (Juan de la Cierva Program) and to the Spanish Ministry of Education and Science for the grant awarded to Betina Piqueras-Fiszman.

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THE CONTRIBUTION OF SCIENTIFIC STUDIES ON PHYSICAL PROPERTIES

Appearance, texture, and other food properties are major components of food quality (Bourne, 2002). It is possible to measure color and several mechanical properties fairly accurately in a laboratory, although the relationship between these results and the in-mouth perception of a food item is sometimes very loose. In terms of quality control, however, it is interesting to measure and monitor the properties of food products. Instrumental methods are quicker, cheaper, and easier to apply than sensory methods.

Some instrumental measurements are very easy to interpret in sensory terms. For example, titratable acidity (pH value) is closely related to the perception of acidic taste, so monitoring the decrease in acidity during yogurt preparation or storage is a good predictor of acid taste perception. The same applies to rising pH values as fruit ripens during storage. Another example is the close relationship between the evolution of degrees Brix (an index of sugar content) and changes in the perception of a sweet flavor. However, these simple examples cannot illustrate the complexity of certain food matrices where it is normal to find a high sugar content masking and lowering the acid flavor perception, obviously without any change in the instrumental measurement.

Other instrumental measurements such as humidity content, water activity, fat rancidity level, microorganism count, or the assessment of a number of compounds by high-performance liquid chromatography–mass spectrometry or gas chromatography can be used to follow the changes that occur during the food's preparation and shelf life.

It is the researcher's task to ascertain and evaluate reliable relationships between the instrumental results and the sensory changes. The literature includes a large number of research papers that establish correlations between instrumental and sensory parameters. Normally, the authors highlight cases in which good correlations are observed but do not report the cases of poor correlation.

The Importance of Texture Measurements

Among the sensory properties of food, texture is possibly the most complex. Applying the texture concept to food—or, indeed, to any material other than textiles—is relatively recent. With reference to food in particular, texture studies cover a number of characteristics related to its nature, composition, and structure and perceptions before and during ingestion. Consequently, it is possible to affirm that food texture is a sensory property (Szczesniak, 2002).

Texture measurements entail taking into account a series of actions, stimuli, and perceptions during the act of eating, or even before, when touching or handling the food item. The stimuli range from the tactile sensation perceived when a knife is used to cut a loaf of French bread, the sound perceived during the first bite or the initial cracking of the crust, to the great number of in-mouth sensations that arise during mastication and mixing with saliva: consistency, adherence, viscosity, ease of swallowing, or oral coating (Lenfant, Loret, Pineau, Hartmann, & Martin, 2009).

During the 20th century, academia and industry developed a battery of texture analyzer instruments to quantify the effects on texture of variables such as raw materials, ingredients, processing, or storage in a reproducible manner. Over the years, equipment designed to measure a single property in a specific type of food has been replaced by universal, versatile texture analyzers. These use a wide range of probes to imitate a series of actions such as puncture, cutting, compression, penetration, extrusion, etc. Normally, a monitor registers the complete force (or deformation) versus time curve that shows how the mechanical behavior of the sample evolves during the test.

The importance of these properties for consumer acceptance has been realized and increasing attention is being paid to correlating instrumental and sensory evaluations. Most modern texture analyzers apply uniaxial deformation perpendicular to the food item at a constant speed in all of the tests. However, human beings unconsciously vary the magnitude and speed of the forces applied during mastication, adapting them to the different types of food (stimuli). Even for the same food, the process of converting a bite-size piece into a bolus ready to swallow is a dynamic process that involves a gradual reduction in mechanical resistance (Albert, Salvador, Schlich, & Fiszman, 2012). In addition, the speed of the jaw movement and the number of bites before swallowing are variable. Other factors that have to be taken into account in instrumental measurements are temperature (in-mouth temperature is around 35°C); the lubricating and dissolving effect of the saliva, which facilitates chewing; the different shapes of the teeth; etc.

In this world of multiple sensations encompassed by texture, many instrumental measurements have focused on measuring mechanical resistance to the first bite with the incisors or molars. The choice of a suitable probe and test speed generates a number of values, but these do not describe the food product's characteristics if analyzed independently. Only their integrated study, analyzing the complete mechanical curve, gives the real "fingerprint" of the food.

Approaching the Two Worlds

Despite the technologies available and the laboratory results, a question that still remains unanswered is how the culinary sector can benefit from this kind of laboratory-based measurement. The reality is that many of these findings are read by only a limited number of chefs and consequently only make it through the doors of a small number of restaurant kitchens. It is no wonder that these restaurants are considered to be followers of molecular gastronomy (also called the *scientific kitchen movement*). For instance, chef Heston Blumenthal employed a texture analyzer and an acoustic envelope detector to help him perfect classic dishes. With the help of Professor Malcolm Povey (professor of Food Physics at Leeds University), he combined science and cookery in order to create the perfect crispy fish batter. Professor Povey and Blumenthal tested batter to identify what constitutes ideal crispness and produce the ultimate batter—one that hardens on the outside while steaming the fish gently from within.

Crispness and crunchiness in foods are associated with fresh products (as in French bread) or recently harvested fruits and vegetables. Crispy/crunchy textures are often used to generate creative or contrasting textural combinations, like nuts in salads or croutons in soups. Recent developments in the art of cooking have been imparting new textures to traditional preparations or combining various textures in the same dish, even from the same raw material; for example, combinations of orange gelatin, sliced fresh orange, candied orange peel, orange jam, caramelized orange, orange sherbet, or orange ice cream (Varela & Fiszman, 2012b). The perception of crispness is related to auditory sensations (all crispy/crunchy foods are noisy). Scientifically, crispy/crunchy textures can be studied by recording the sounds emitted by the piece of food while it is being compressed or cut (Chen, Karlsson, & Povey, 2005; Varela, Chen, Fiszman, & Povey, 2006). Povey pioneered the acoustic envelope detector, which measures the burst of sound generated when food is bitten into or snapped. In a number of studies, the integrated study of energy dissipation processes has been approached by coupling sound emission analysis with mechanical measurements. This is crucial for understanding the crispy/crunchy nature of solid foods (Varela, Salvador, & Fiszman, 2008; Varela, Salvador, Gámbaro, & Fiszman, 2007).

The effect of the acoustic factor on the sensory perception of crispness has been studied in two ways: through airborne chewing sounds or a combination of mechanical tests and acoustic recordings. The airborne sounds were studied by playing prerecorded chewing sounds to subjects and asking them to evaluate their acoustic properties or by asking subjects to evaluate the sound produced by biting or chewing crispy/crunchy food items. These methods have been useful for developing definitions of sound-related sensory terms (loudness, pitch, duration of the sound, etc.) and have also stimulated discussion about what is crispy and what is crunchy. Flexure (three-point bending tests), compression, and puncture tests have been used to measure texture while recording the sound produced at fracture (Varela & Fiszman, 2012a).

Instrumental texture measurements are undoubtedly in many ways a valuable tool for food development, but it is necessary to know and accept their limitations in comparison to sensory evaluation.

THE CONTRIBUTION OF SCIENTIFIC STUDIES ON SENSORY ASSESSMENT AND CONSUMER PERCEPTION

Grasping Consumer Insights

For decades, consumers have only been considered capable of hedonic judgments (Meilgaard, Civille, & Carr, 1999; Stone & Sidel, 1985). However, in order to design food products that meet consumers' sensory expectations, information is needed about how they perceive the sensory characteristics of the products (ten Kleij & Musters, 2003). In recent years, several methods for gathering information about consumer perceptions of the sensory characteristics of food products have been developed. In particular, word association and free listing have proven to be powerful projection tools for discovering consumers' sensory perceptions (Adams, Williams, Lancaster, & Foley, 2007; Ares, Barreiro, Giménez, & Gámbaro, 2010; Faye et al., 2006; Narain, Paterson, & Reid, 2004; Pagès, 2005; Perrin et al., 2008; Popper, Rosenstock, Schraidt, & Kroll, 2004). From this point of view, an understanding of how consumers describe the sensory characteristics of food products is very valuable. Texture terms could be a suitable way to communicate the sensory characteristics of a food product to consumers.

Several studies have been carried out to identify consumers' texture vocabulary in different languages. From Yoshikawa, Nishimaru, Tashiro, and Andyoshida (1970; Japan), Szczesniak and Kleyn (1963; United States), and Rohm (1990; Austria), it was concluded that the most frequently used terms in the three languages are similar, although Japanese is the language with the richest textural vocabulary. Lawless, Vanne, and Tuorila (1997) compared sensory texture terms in Finnish and English and concluded that texture dimensions are consistent between these two cultures. However, cross-cultural differences in consumer perceptions of texture terms have been reported within the same language (Varela, Salvador, Gámbaro, & Fiszman, 2008).

In an international study, participants from Spain, Argentina, and Uruguay were asked to list all of the texture characteristics of food products that they knew. More than 100 terms were elicited from the consumers, mainly comprising words related to the texture characteristics of food products. By simultaneously considering frequency of mention and the average order of the elicited terms, the most familiar texture terms in each country were identified. The consumers mainly mentioned texture terms according to their relevance to everyday life rather than according to the sensory characteristics to which they are related (Antmann et al., 2011a).

Case Studies of the Consumers' Perception of Creaminess—A Complex Textural Attribute

Creaminess is a complex textural attribute. When presented with a creamy food product, consumers expect certain hedonic and sensory characteristics.

When the product is tasted, these expectations are unconsciously compared to the product's real attributes, leading to their confirmation or disconfirmation (Deliza & MacFie, 1996). If the sensory characteristics of the product are as the consumer expects, he or she is likely to consume the product again. Failure to fulfill these expectations will very likely cause disappointment and the consumer will probably not repeat the experience. Considering the importance of creaminess in consumers' overall liking of many food products, when designing a creamy food it is crucial to understand how creaminess is perceived, what consumers expect when a product is described as creamy, and how to describe it using words and attributes that are relevant to consumers.

Several international studies have been undertaken to identify which characteristics are associated with a creamy product. Projection techniques have been used with participants from Spain, Argentina, and Uruguay. Using word association tasks, the consumers were asked to write down the first four words, descriptions, associations, thoughts, or feelings that came to mind when thinking of creaminess (Antmann et al., 2011b). The consumers mainly associated creaminess with creamy food products and with texture, flavor, and appearance attributes such as smoothness, softness, sweetness, and pleasantness. Differences were found between results of Spanish and Uruguayan consumers, indicating that cultural differences in consumers' understanding of the term *creaminess* exist even within the same language.

In another study (Antmann, Ares, Varela, Salvador, & Fiszman, 2011), consumers were asked to define creaminess and to list all of the creamy products they knew and all of the sensations they perceived when consuming a creamy product. Their perceptions of creaminess seemed to be mostly related to tactile and kinesthetic sensations such as smoothness, viscosity, melting, and softness, as well as to hedonic, pleasant sensations. The study also showed an important correlation between creaminess and sweetness and a strong association between creaminess and pleasure. This work contributed to a greater knowledge of the vocabulary used by consumers to describe the texture of food products. Differences were found between Argentine, Spanish, and Uruguayan consumers' use of the same words, again showing the existence of intralinguistic cross-cultural differences.

Understanding what consumers expect from a creamy product and what expectations are raised when they think of creaminess could help to ensure that expectations are fulfilled. Identifying which attributes are relevant to consumers and using them in the claims for the product could also increase the probability of success of new products and dishes. Dairy products seem to be products that consumers in the three countries most frequently expected to be creamy.

How to Study the Influence of Non-sensory Factors on Food Choice?

Recently, consumer science has become an important tool for the food and hospitality industries. It is widely agreed that though the appreciation of taste and other sensory qualities are very important, they are only a part of consumers' food-related behaviors (Jaeger, 2006). In addition to the sensory aspects of a food, techniques that examine non-sensory factors influencing consumers' food choices are of particular interest. These non-sensory factors are contextual, nutritional, practical, psychological, and socioeconomic. They include knowledge and beliefs, attitudes toward novelty (new technologies, processes, genetically modified organisms, etc.), culture, moods, emotions, memory, and attention.

Apparently consumers use a personal food system; that is, a dynamic set of processes directed toward making food choices. The five main food-related values are taste, health, cost, time, and social relationships. Other less prominent ones are symbolism, ethics, variety, safety, waste, and quality (Connors, Bisogni, Sobal, & Devine, 2001).

It is well known that liking is highly dependent on context. Eating in a restaurant is undoubtedly a multisensory experience (appearance of the food, smell, sound, texture as well as non-sensory factors that have a great influence and have been studied less by academics). The expectations raised by a five-star restaurant and a corner coffee shop are not the same, and depending on the occasion one will be preferred over the other. The ambience, atmosphere, decoration, neighborhood, etc., could be important factors that influence the decision, but the same food would not be chosen for a romantic dinner, a business lunch, and a Friday night out. Menus can vary in their elements of surprise, complexity, or variety but also in their information, design, or pictures. The staff's interaction with the guests, the timing between courses, and the music can play important roles in developing preferences.

Variety is an important parameter in food choice. A large-scale study of attitudes toward food across six Euro-American cultures has provided a better understanding of preferences. The results suggest that the United States, and the UK to some extent, focus on providing choices that cater to individual differences in preferences—in other words, a large variety of options in a fine restaurant—whereas continental European countries are more attached to communal eating values and consider that in an upmarket restaurant the menu should include a few, good options (Rozin, Fischler, Shields, & Masson, 2006). Culture underlies all food choices and acts as a basis for the development of preferences. Family and friends provide models, and peer pressure, for consuming particular foods and trying new foods. Social facilitation is an important factor in what and how much is eaten. Research indicates that the social facilitation effect leads to lower levels of food consumption when people eat alone and to higher levels when eating in a group, especially with familiar people (Nestle et al., 1998). Eating a meal can influence mood and emotions, typically reducing arousal and irritability and increasing calmness and positive affect. Nevertheless, this depends on the meal size and composition, expectations, and needs. A meal that is too small or unhealthy might negatively affect mood. Sweetness and sensory cues to high energy density, such as a fatty texture, can improve mood and mitigate the effects of stress (Gibson, 2006). Nutritional knowledge is an important factor in explaining variations in food choice, which is why, in Europe, including this information has been a target for health education campaigns aimed at promoting healthy eating (Wardle, Parmenter, & Waller, 2000). Ethics and values can influence the selection of organic, free-range, or vegetarian food. Environmental and animal rights issues, as well as politics, can have a strong influence on attitudes toward, for example, organic food. Honkanen, Verplanken, and Olsen (2006) suggested that the more people are concerned about these issues, the more positive their attitude toward organic food and the more likely they would be to consume it.

Special tools are required to assess non-sensory consumer perception. According to Ogilvy (1963), consumers do not always behave as they say, say what they think or think what they actually feel. Therefore, consumer science goes further than just asking opinions; the objective is to discover the reasons underlying food choice. Explicitly measured attitudes are particularly valuable for predicting deliberate, controlled behavior. In contrast, implicitly measured attitudes are considered more important for predicting impulsive behavior (Friese, Hofmann, & Wänke, 2008). To discover which information or design features in a restaurant menu set up particular expectations and reactions in consumers, for example, tools that measure attention can be used, like eye-tracking tools (Goldberg, Probart, & Zak, 1999), reaction measurements, or face reading (de Wijk Kooijman, Verhoeven, Holthuyzen, & de Graaf, 2012). They can also be used for emotional response measurements, together with other techniques such as electromyography, vocal measurements, or brain scans (Wang et al., 2004).

The most common approach to measuring food choice–related attitudes explicitly is through questionnaires specifically designed for each type. These include the Food Choice Questionnaire (Steptoe, Pollard, & Wardle, 1995), the Nutritional Knowledge Questionnaire (Parmenter & Wardle, 2000), the Food Neophobia Scale (Pliner & Hobden, 1992), Food Involvement scales by various authors (Marshall & Bell, 2002), the Variety Seeking Tendency Scale (van Trijp & Steenkamp, 1992), and Food Related Lifestyle (Brunsø & Grunert, 1998). Food-related emotions or moods can also be self-rated by consumers using specifically designed questionnaires that employ words or images, such as the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988), the Profile of Mood State (POMS; McNair, Lorr, & Droppleman, 1971), Bond-Lader visual analogue scales for mood assessment (Bond & Lader, 1974), the Product Emotion Measurement Tool (PrEmo®, 2000), or a questionnaire with a specific focus on food products recently developed by King and Meiselman (2010).

From the Probe to the Mouth

As may be sensed at this point, the collaboration between the laboratory and the kitchen is not limited to modifying flavors or creating inconceivable textures and serving them to the diner. In many cases, serious studies with consumers are required. For example, returning to the role that auditory cues can play in modulating the perception and evaluation of foodstuffs, Zampini and Spence (2004, 2005) demonstrated in the laboratory that people's ratings of the crispness of potato chips and the carbonation of a fizzy beverage (cf. Chandrashekar et al., 2009) can be modified by the crisp biting or fizzing sounds they hear. Participants in the study bit into potato chips with their front teeth while rating either their crispness or freshness using a computer-based visual analog scale. Importantly, they had a microphone in front of them connected to a headphone that they were wearing. The results demonstrated that the perceptions of both crispness and staleness were modified by varying the loudness and frequency composition of the auditory feedback during the biting action. The potato chips were perceived as being significantly crispier and fresher when either the overall sound level was increased or when just the high-frequency sounds (2–20 kHz) were amplified. Similar results were observed when participants rated a series of sparkling water samples in terms of their perceived carbonation using a visual analog scale. These results highlight the significant role that sounds can play in modulating the perception and evaluation of food and beverages (although consumers are often unaware of the influence of such cues). In a similar vein, Woods et al. (2011) recently suggested that background noise may simply "mask" taste perception. In particular, they found that food properties unrelated to sound (or not perceived through hearing, like sweetness or saltiness) were diminished when there was background sound (as opposed to silence). In contrast, crunchiness appeared to be enhanced in this situation.

From the Probe to the Table

Recently, more experiments are investigating effects obtained in the lab in more natural and ecologically valid settings (e.g., restaurants, ready meals at home, catering events, etc.). One intriguing example was Blumenthal's collaboration with Spence to develop the "Sound of the Sea" seafood dish at the Fat Duck, in the UK, which is supposed to be consumed while wearing headphones connected to a hidden player that plays sounds of the sea (Spence, Shankar, Blumenthal, 2011). The dish has become one of the restaurant's signature dishes. Previous experimental research in the laboratory had demonstrated that oysters were rated as significantly more pleasing while listening to this soundtrack than while listening to farmyard sounds.

As mentioned above, recent research has delved into the influence of extrinsic factors on food perception. This is particularly relevant to the culinary sector. Though a number of recent reviews have highlighted the importance of atmospheric/environmental cues in determining what, how much, and how quickly people eat and drink, and even how much they report liking the experience (see Stroebele & de Castro [2004] for a review), there has been far less research on the role of tableware in eating, drinking, and flavor perceptions. Piqueras-Fiszman and Spence have been carrying out a series of experiments on how the material properties of the cutlery and tableware that accompany the food at each meal bias consumers' perception of foods and beverages (see Spence, Harrar, & Piqueras-Fiszman [2012] for a review). To mention only two examples, they showed how much of an impact the color of the plate can have on the perception of the food placed on it (Piqueras-Fiszman, Alcaide, & Spence, 2012) and that the haptic information (from the sense of touch) received while eating can affect perception of the specific texture attributes of what is being eaten (Piqueras-Fiszman & Spence, 2012). These findings highlight the significant effect that the nonedible components of eating and drinking (e.g., the cutlery, crockery, glassware, condiment containers, menus, or atmosphere) can have on people's perceptions of, and responses to, foods and beverages. These effects will soon be tested in a restaurant setting with real diners to determine whether the same effects are observed.

THE CONTRIBUTION OF SCIENCE TO THE CULINARY EXPERIENCE—CONCLUDING REMARKS

Creative cuisine derives from an exchange of expertise by cooks, food scientists, designers, and psychologists. Previously unimaginable textures and unexpected flavors and aromas are now being combined and served in novel formats and settings in order to create unique multisensory culinary experiences that provoke some sort of reaction in the diner. Thanks to the union of these disciplines, chefs have a wider array of resources to deliver the intended experiences, whether via the food or via the surrounding items and the ambience. One certainly does not go to one of these restaurants just to eat. One goes there to enjoy the theater (cf. Pine & Gilmore, 1998, 1999) or the multisensory experience in every single morsel of food (Adrià, Soler, & Adrià, 2007; Blumenthal, 2008; Martin, 2007). Hence, the innovative chef always needs to be on the lookout for new ways to deliver surprises (Svejenova, Mazza, & Planellas, 2007), constantly striving for the next "new thing" in a nonstop process of inspiration, innovation, and multidisciplinary research.

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