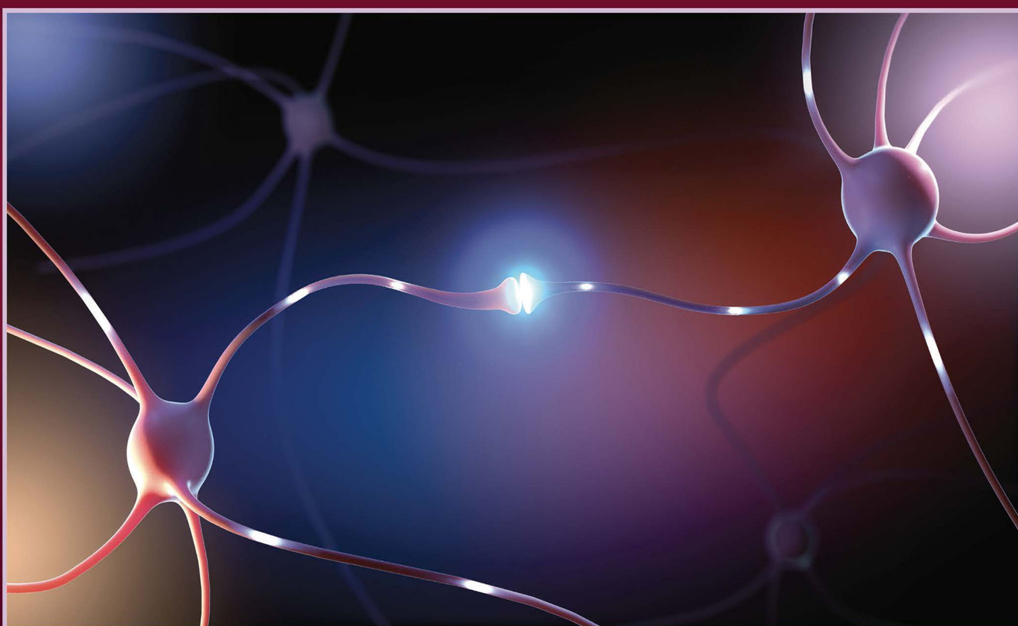
Contemporary Food Engineering Series

Engineering Innovations in Sensory Science



Edited by

Mahendran Radhakrishnan
Anbarasan Rajan

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Engineering Innovations in Sensory Science

Sensory analysis is significant in food product development, and its importance impacts the maintenance of sensory qualities for food products. While there are many books exploring sensory analysis and its methods, this is the first of its kind to also explore the use of engineering tools and instruments to produce measurable and reliable data. In exploring sensory analysis methods, this book also focuses on the novel computer interface technologies to retrieve human sensory perceptions directly from the human body and convert them into a measurable unit, exploring the present status in computer interface technologies and scope for interventions to overcome obstacles.

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Contemporary Food Engineering

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The **Contemporary Food Engineering Series** will consist of edited books addressing engineering processes related to food production. Classical unit operations in engineering applied to food manufacturing will be covered as well as such topics including the transport and storage of liquid and solid foods; heating, chilling and freezing of foods; mass transfer in foods; dehydration, thermal processing, non-thermal processing, extrusion, liquid food concentration, membrane processes and applications of membranes in food processing; packaging, cleaning, and sanitation. The books will be aimed at professional food scientists, academicians researching food engineering problems, and graduate level students.

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Engineering Innovations in Sensory Science

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Contents

Preface

One of the most important aspects of a food product is its appeal to consumers, often referred to as sensory acceptability. This concept encompasses the degree to which a food is considered desirable based on its sensory properties, such as taste, smell, texture, and appearance. In the food industry, products are processed not only to enhance their edibility, nutritional value, and safety but also to achieve desirable organoleptic qualities. Just like any other quality parameter, sensory characteristics must be carefully maintained during industrial-scale production. To ensure uniformity across production batches, industries rely on trained sensory panels to evaluate and maintain consistency in sensory attributes.

Over the years, industrial production has undergone significant transformations, from the advent of steam-powered processes to the integration of artificial intelligence and human-centric approaches. Similarly, sensory analysis has evolved from traditional subjective methods to the adoption of instrumental techniques such as electronic noses (e-noses) and electronic tongues (e-tongues). While these advanced techniques offer notable advantages, they also come with certain limitations. As industries continue to evolve rapidly, it is imperative to upgrade sensory evaluation approaches to align with emerging technologies and advancements.

This book aims to present innovative concepts that merge human sensory perception with instrumental analysis, enabling the generation of comprehensive sensory data. One of the key ideas explored is the inclusion of everyday consumers, beyond trained panels, in sensory evaluations. By engaging a larger and more diverse pool of participants, these approaches hold the potential to minimize biases and provide richer sensory insights. Furthermore, these techniques open up opportunities to capture sensory data from diverse groups, including babies, children, and elderly individuals, ultimately facilitating the development of specialized food products tailored to various demographic needs.

The book comprises 13 chapters, each delving into three distinct eras of sensory evaluation techniques: traditional human-based methods, instrument-based techniques, and the emerging collaborative approaches that integrate humans and instruments. We believe readers will gain valuable insights from this book, paving the way for future research in these innovative areas. The ideas presented here are intended not as an exhaustive summary of the field but as a starting point to inspire and empower researchers to harness the potential of technological innovations in sensory science.

We hope this book serves as a driving force for advancements in the field and invites readers to explore the exciting possibilities of merging tradition with technology in sensory evaluation. Together, with your support and expertise, we can unlock the full potential of this fascinating discipline.

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History and Importance of Sensory Science

1

Herbert Stone and Rebecca N. Bleibaum

1.1 INTRODUCTION

Sensory evaluation measures the reactions of people to products as perceived by the senses. It is a unique information source not easily obtained by other means. It connects the consumer with product technology and preferences in quantitative terms. What makes it unique is the testing uses limited numbers of subjects, in most situations 25 to as few as 10. Some tests take less than a day to complete while others could take as much as one to two weeks based on the number of products and kinds of information obtained. To achieve this degree of effectiveness, one needs resources such as qualified subjects, a selection of appropriate methods, defined research objective, data plan, and priority. This chapter identifies the early research that led to the field of sensory and consumer evaluation as we know it today. For information about this early research, the reader is directed to Amerine, Pangborn, and Roessler (1965), Heymann (2019), Laming (1986), Pangborn (1981), Meiselman et al. (2022), and Stone, Bleibaum, and Thomas (2020). Note that many of the early publications are not readily available, so these recent publications provide summaries of relevant sections.

1.2 WHAT IS SENSORY EVALUATION AND WHY IS IT IMPORTANT?

Sensory evaluation is a multidisciplinary science that focuses on the study of human responses to products or stimuli. It is widely applied to foods, beverages, home and personal care products, and many consumer product categories.

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In product development, understanding sensory preference differences enables companies to optimize formulations and create products that better meet consumer expectations. In quality control, sensory can help ensure that products maintain consistent sensory characteristics, providing a more reliable and standardized product experience for consumers. Sensory information can help companies better understand consumer satisfaction, and specifically what they like or dislike about their products. By aligning products with consumer preferences, companies can enhance overall satisfaction with the brand. Sensory information can help identify market trends and innovations such as the impact of more available healthier food options.

In today's world companies regularly change product formulations, manufacture and ship products across multiple regions, look for alternative suppliers of ingredients and packaging, or they change a technology, equipment, or process. Companies benefit by having sensory and consumer information about their products and their competition to support decision-making.

Sensory data is used to understand perceptions and efficacy in lotions, shampoos, perfumes, cleaning products, fabrics, and textiles, automotive care, sporting equipment, for example. There are a host of agricultural challenges that benefit by having sensory and consumer data, such as sustainability, food waste, and changing growing conditions. Various textbooks discuss broad applications, including Delarue, Lawlor, and Rogeaux (2015), Beckley, Lopetcharat, and Paredes (2022), Pensé-Lhéritier, Bacle, and Delarue (2021), Civille and Carr (2015), Stefanowicz (2013), and Stone, Bleibaum, and Thomas (2020).

1.3 THE EARLY YEARS, WEBER, FECHNER, AND THE JUST-NOTICEABLE DIFFERENCE (JND)

In this time period of the 1850s, experimental psychology was emerging as a unique discipline focused on measuring human sensory skills and whether this behavior could be explained in mathematical terms. Weber and Fechner, published research on detection of differences leading to the concept of the just-noticeable difference (JND), and this provided the foundation for modern psychophysics and measurement of human perception.

The experiments conducted by Weber were based on the perceived weight of objects held in the hand, to understand the smallest differences in weight for objects of different masses. Fechner further developed Weber's research in psychophysics, outlining the relationship between physical stimuli and the perceptions and sensations they elicited. Fechner (1860) introduced the concept of JND which he referred to as the difference threshold. He also proposed using these methods for vision, hearing, and touch and introduced the notion of logarithmic relationship between the perceived sensation and physical stimulus intensity, known as Fechner's law.

The concept of JND is fundamental to the field of psychophysics and it continues to be influential in our understanding of sensory perception. For additional discussion about this early research on the JND, the reader is directed to Boring (1950), Girardot, Peryam, and Shapiro (1952), Lundgren et al. (1976), Stone and Bosley (1965), Amerine, Pangborn, and Roessler (1965), Laming (1986).

1.4 DEVELOPING MEASUREMENT SCALES AND STATISTICAL ANALYSES

S.S. Stevens, like Fechner, worked in the area of psychophysics, and he created the Stevens' power law which revisits Fechner's law by showing that perceived intensity of a stimulus is in fact related to exponentially rather than logarithmically to the physical magnitude of the stimulus. The article, "On the Theory of Scales of Measurement" (Stevens 1946), had a lasting impact on the field. Measurement is the assignment of numerical values to objects or events according to some rules, and he formulated the rules for nominal, ordinal, interval, and ratio scales (Stevens and Galanter 1957).

The scale types are important in sensory research as each scale is treated differently with statistical approaches. The nominal scale lacks numerical properties and is used as an assignment of a category, such as marital status or gender. Simple statistics and frequency values can be summarized. Ordinal scales allow ranking of observations in a specific order. The relative magnitude of difference between ranks is not necessarily equal and this scale does not provide any measure of magnitude between the categories (Stevens 1962). Preference ranking uses ordinal scales (example prefer first, second, and third), although there is no indication of magnitude between preference ratings. Interval scales are widely used in sensory research as these scales have no true zero point and mathematical operations such as addition and subtraction are meaningful. Examples include the unstructured graphic rating scale used in descriptive analysis (Figure 1.1) which allowed for a statistical approach to understand product differences and to assess panel performance.

The 9-point hedonic scale (Figure 1.2), although not a true interval scale, is treated as such for analysis purposes and is discussed in more detail later in this chapter.

The last classifications of Stevens' ratio scales have a true zero and include measures such as height, weight, time, and money.

Stevens presented the idea that a particular scale determines the permissible mathematical operations for each scale. The scales are distinguished based on the distance properties and inherent in the properties of numbers and how they are assigned. The scale classification proposed by Stevens is still widely used (Stevens 1951), although Coombs thought it was too restrictive (Coombs 1964).

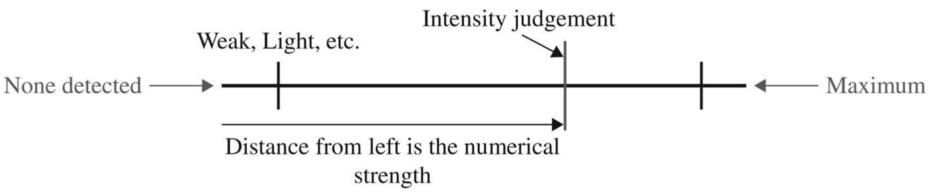

FIGURE 1.1 Unstructured graphic rating scale used in QDA.

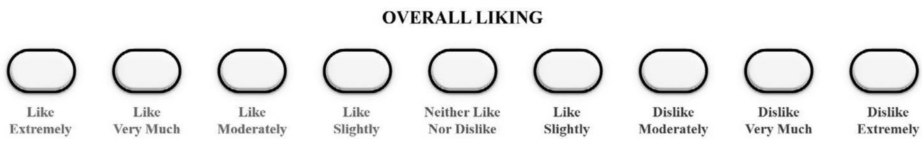

FIGURE 1.2 The 9-point hedonic scale.

Continued study of the senses using scaled measurement and statistical analysis, especially related to vision and audition, enabled better understanding of human behavior. Use of vision and audition as the stimuli were especially popular because it offered practical applications such as control of amounts of each stimulus. For those interested in some of the relevant research in this time period, see Guilford (1954). Thurstone (1959) also reported results from a series of pioneering psychophysical studies involving attitudes about social issues and included tests about food. One of Thurstone's key contributions was the development of statistical techniques for multiple-factor analysis of human performance in psychological tests; analyses which are still used today. One of the first sensory tests was described.

As the consumer goods industry competition was developing, companies were giving more attention to monitoring production with sensory evaluation procedures. Based on the popularization of the 9-point hedonic scale used to access military rations for soldiers, the need for information about food acceptance was also attracting corporate attention (Cover 1936). Laboratories in the USDA were established with a focus on food evaluations (Boggs and Hanson 1949; Dawson and Dochterman 1951); the Flavor Profile method was described (Cairncross and Sjostrom 1950) and publications describing new methods on the measurement process itself (Garner and Hake 1951; Stevens 1951; Girardot, Peryam, and Shapiro 1952; Guilford 1954; Dawson 1955; Garner 1960; Peryam 1991; Thurstone 2017).

In addition to sensory methods development in discrimination testing, consensus and Quantitative Descriptive Analysis, and temporal methods, along with an array of consumer research methods was being studies and applied. Specific research about the qualification criteria, including an individual's threshold for substances, sensory acuity screening with model basic taste solutions, and number of persons to serve as subjects was being discussed and debated. Surprisingly these topic remains controversial in contemporary sensory practices. In a lecture on the topic, Pangborn (1979) noted "Contrary to popular belief, there are no data to verify that a person's threshold to dilute solutions of compounds representing the 'basic' taste (e.g., sucrose, tartaric acid, sodium chloride, caffeine) is related to sensitivity or reproducibility of responses to sensory properties of complex food systems" (for more on this topic, see Girardot, Peryam, and Shapiro 1952; Mackey and Jones 1954; Sawyer et al. 1962; Baroshuk 1978; Pangborn 1979; Gomez-Lopez 2023).

1.5 THE PAIRED COMPARISON AND OTHER DISCRIMINATION TEST METHODS

During the 1940s, more aggressive research on sensory discrimination testing with food as the stimulus was conducted by Peryam and associates. The discrimination methods included the triangle, the duo-trio, and dual standard tests Seagram's Distillery in Louisville, Kentucky. Independently, researchers at the Carlsberg Brewery Labs in Denmark also published their research on the use of the triangle test method in 1946.

Discrimination tests are designed to determine if a difference is perceived between two products. In the triangle test, subjects are provided with three coded samples, two of which are the same and one is different. The subject's task is to identify which sample is different from the other two. In the duo-trio test, subjects are presented with one reference sample and two coded samples, one of which matches the reference. The subject's task is to identify which of the two coded samples matches the reference.

These tests are commonly used for shelf life and stability testing. The example in Figure 1.3 illustrates duo-trio testing of the same product pair at four test intervals – 0 time, three, six, and nine months. No differences were detected between the products until the nine-month interval. These tests are also used for ingredient substitutions, packaging, among other applications.

These methods enabled researchers to obtain actionable results. Discrimination tests, including triangle, duo-trio, paired comparison, multi-standard, and tetrad are valuable sensory tools for determining perceived differences between products. The choice of methods depends on the research objectives. Discrimination test results confirm differences between products can be identified, but they will not identify the magnitude nor nature of those differences.

Based on the limited scope of information provided by discrimination tests, there was need for more detailed product information on the nature of the perceived differences. Arthur D. Little published the Flavor Profile method, a standardized way for flavor description, to aid in product understanding (Caul 1957). The impact and importance of the Flavor Profile method will be discussed in more detail in the descriptive analysis section, later in this chapter.

	0 Months	3 Months	6 Months	9 Months
# Correct / Total	23/50 Rep 1: 12/25 Rep 2: 11/25	26/50 Rep 1: 14/25 Rep 2: 12/25	29/50 Rep 1: 14/25 Rep 2: 15/25	34/50 Rep 1: 16/25 Rep 2: 18/25
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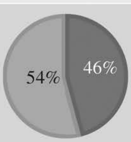
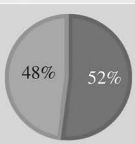
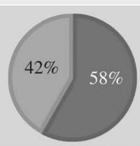
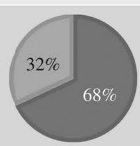
Graph (darker green = % correct)				

FIGURE 1.3 Example of a six-month shelf-life discrimination test (duo-trio) at four time points.

1.6 THE 9-POINT HEDONIC SCALE AND OTHER METHODS

In 1950, Thurstone and coworkers developed the 9-point hedonic scale for measuring product preferences specifically for military use (the US Quartermaster Food and Container Institute located in Chicago). This effort was driven by the poor acceptance of US Army rations during WWII. For more information about the method, readers are directed to the work of Thurstone and others. (Jones, Peryam, and Thurstone 1955; Jones 1959).

The 9-point hedonic scale was adopted by early researchers, including Rose Marie Pangborn who studied consumer liking of an array of canned fruits, demonstrating that the scale could be used by real consumers, in addition to soldiers (Valdes and Roessler 1956; Simone et al. 1956; Pangborn and Leonard 1958). The scale allowed panelists to rate food items on a scale of 1–9 based on their liking or disliking using descriptors such as like extremely (9) to dislike extremely (1), and so on. Panelists would taste and evaluate different food products, providing numerical ratings to indicate their hedonic preferences, allowing for statistical analysis of the resulting data.

The 9-point scale became widely used in research and a key measure for product liking and has been translated into multiple languages. This scale remains a standard tool in sensory evaluation and is often supplemented with other questions such as purchase interest and meets expectations to better gauge consumer interest (Figure 1.4).

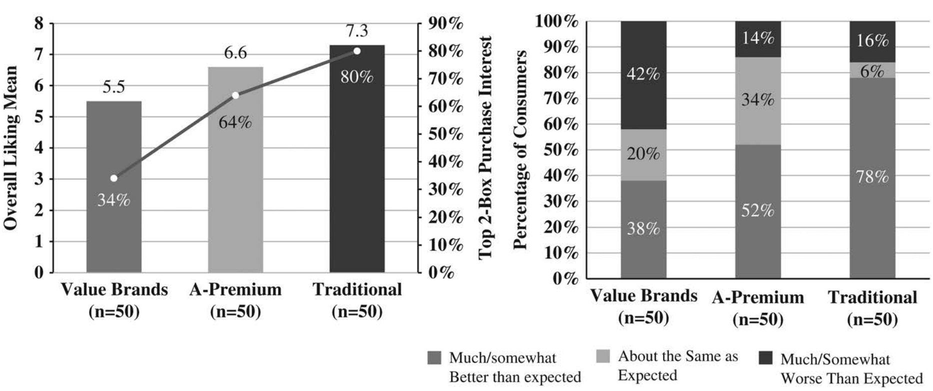


FIGURE 1.4 Example of small-scale product test with 50 consumers.

1.7 ACADEMIC ACHIEVEMENTS AND RECOGNITION

Maynard Amerine was an influential American enologist and wine scientist who made significant contributions to California's wine industry. He, along with his colleagues conducted extensive research in wine chemistry, sensory analysis, and winemaking techniques. He earned his PhD in Agricultural Chemistry from the University of California at Berkeley in 1935 and then joined the faculty at UC Davis as a professor in the Department of Viticulture and Enology.

It was his pioneering research in the cultivation, fermentation, and sensory evaluation of wine that helped him gain notoriety. Amerine was working at UC Davis with colleagues Edward Roessler, who developed the Division of Mathematics and Physics and taught statistics at UC Davis, and Rose Marie Pangborn, a food scientist, professor, and pioneer in sensory science. This trio investigated the taste of wine, developing and refining sensory methods and teaching a course in sensory evaluation. Based on their years of work together, they also wrote a seminal textbook, *Principles of Sensory Evaluation of Food*, 1965, and their work has had a lasting impact on wine and food education, research, and industry practices.

In 1955, Rose Marie Pangborn began teaching the first sensory evaluation course at UC Davis. This class served as the foundation for the sensory curriculum that trained so many sensory professionals then and continues to this day. Herbert Stone, then a PhD candidate was her first teaching assistant and helped develop the laboratory assignments. The program included sharing concepts such as experimental design, measurement, test methods, data analysis, and communicating results to enable students to succeed in their careers in academia and industry. "She is credited as being the foremost pioneer in the field and participated in seminars world-wide. She trained some of the top professionals in the field, who have continued her work" (Meiselman et al. 2022).

In 1963, Friedman, Whitney, and Szczesniak, at the General Foods Corporation, published a procedure that made measurements of food texture accessible to anyone with an appropriate instrument (Friedman, Whitney, and Szczesniak 1963). Szczesniak earned her PhD in Food Technology at Massachusetts Institute of Technology (MIT). She is a recognized pioneer in food texture, helped develop the Texture Profile method along with corresponding physical measures with work on the General Foods Texturometer.

In 1968, after having completed his PhD at UC Davis, Malcolm Bourne wanted to develop instrumental methods that better matched the human sensory experience, as there were instrumental limitations and problems with the operation of the General Foods Texturometer. He adapted texture measurements to operate on an Instron Universal Testing Machine (IUTM); however, in the adaptation, changes in the experimental protocol occurred. For example, a Bourne-designed test for evaluating apple firmness was meant to simulate the action of a thumb pressing on the skin, just as a consumer does when selecting fruit at a supermarket (Stone and Pangborn 1968).

1.8 DESCRIPTIVE ANALYSIS – CONSENSUS PROFILE, QDA, SPECTRUM, AND OTHER METHODS

Descriptive analysis is an important methodology for the evaluation of consumer products. Whether one is looking to connect specific sensory attributes with formulation differences or process changes and/or with preferences, results from a descriptive test have had and continue to have a significant impact on the food and beverage industry.

It is a methodology that provides word descriptions of products, either using an everyday consumer language along with measures of intensities for those descriptions such as in QDA or technical language with chemical terms such as the consensus profile methods (Flavor and Texture) and Spectrum. All descriptive methods utilize a small panel; some methods use as few as 6 while others use as many as 20, depending on availability and level of risk associated with the project. Later in this chapter, we will have more to say about subjects.

The earliest formal method, Flavor Profile, was introduced in the late 1940s as a method to enable companies to minimize reliance on a company expert (Cairncross and Sjostrom 1950). Recommended panel size was 6 specially trained subjects. It was offered as a problem-solving resource as well as in support of product development efforts. From a sensory perspective, it demonstrated that a descriptive panel could be developed; however, developing a panel took as long as 3+ months, the language was limited to less than ten attributes, and could not be quantified so no statistical analysis was possible. Instead, results were reported as a consensus decision. This was surprising since research was being reported on various measurement methods (Stevens 1951; Guilford 1954), yet no changes were offered well into the 1970s. These limitations are discussed elsewhere (see, for example, Stone, Bleibaum, and Thomas 2020).

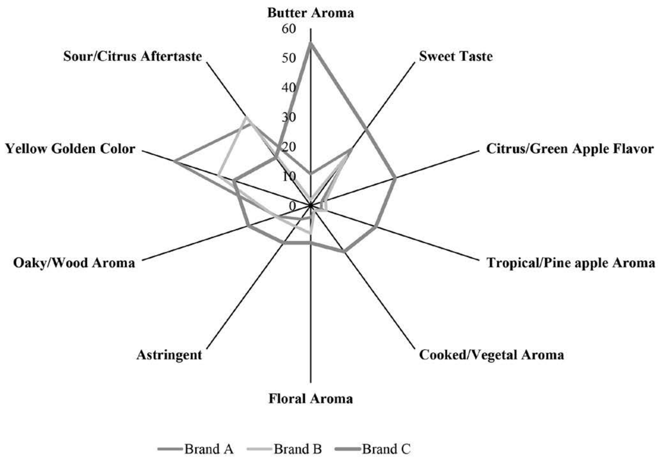
Based on the principles of the Flavor Profile method, the Texture Profile method was developed at General Foods Corporation. The method was expanded to include a wide variety of product types (Civille and Szczesniak 1973; Civile and Liska 1975). The terminology was based on the rheological properties specific for each product. The original method relied on a series of 7- and 9-point scales. Panel verdicts may still be derived from consensus, as with the Flavor Profile method, or by data analysis (Civille and Carr 2015).

The Flavor Profile method has, for the most part, been phased out of use and is now referred to as consensus profiling (see ASTM Manual 13, Second Edition, Bleibaum 2020). However, the fundamentals of using a small group of assessors and the importance of Flavor and Texture Profile to the development of sensory science cannot be underestimated.

In 1974 the Quantitative Descriptive Analysis (QDA) method was described (Stone, et al, 1974, 2004). It was a different approach to descriptive analysis, including use of 12 subjects qualified based on sensory skill, a consumer-based scorecard language, repeated trials designs, quantitative responses, statistical analysis, and a unique display of results – often referred to as spider plots as shown in Figure 1.5. Developing a panel takes 2 weeks: a series of 8 sessions, each lasting 90 minutes. Existing panels need only an orientation session, followed directly by data collection. Data collection time is based on the number of products and priority. For example, a 6-product test requires four 60-minute sessions, usually one per day. However, priority could change the number of sessions to two per day. The number of trials could also be increased or decreased. These decisions are the responsibility of the panel leader, in consultation with the requesters.

With the advent of direct data capture systems, software for analyses and displays, the entire testing process could be completed in less time. Further time savings was realized with increase in chip capacity and notebooks. This enabled panels to evaluate products in typical use situations with data analysis in real time. For details about these developments, the reader is referred to Sidel, Bleibaum, and Tao (2018) and Stone, Bleibaum, and Thomas (2021).

The QDA method created a system that was more reflective of the consumer experience, could be applied to any product category, and was easily adapted as technology changed. The sensory language utilizes a common consumer language for each sensory attribute. Because it uses a consumer-based language, results are easily translatable for marketing and management staff (Figure 1.5). As previously mentioned, each test is completed in a few sessions, and this enables extensive statistical analyses and more robust relationships with populations of interest.



Means Matrix1 (12 Ss, 3 reps)	Butter Aroma	Sweet Taste	Citrus/Green Apple Flavor	Tropical/Pine apple Aroma	Cooked/Vegetal Aroma	Floral Aroma	Astringent	Oaky/Wood Aroma	Yellow Golden Color	Sour/Citrus Aftertaste
Brand A	10.67^b	23.75^b	3.79^b	3.79^b	2.17^b	4.04^b	5.62^b	11.92^b	48.5^a	34.17^a
Brand B	1.96^c	20.54^b	5.25^b	5.62^b	2.12^b	9.42^{ab}	8.75^b	12.33^b	32.83^b	37.00^a
Brand C	54.83^a	31.92^a	30.08^a	23.17^a	19.29^a	12.62^a	15.62^a	22.13^a	27.38^c	20.04^b

FIGURE 1.5 QDA spider plot with panel means table.

Another descriptive method was introduced in the late 1970s, The Spectrum method, developed by Civille and associates. The foundations of this method are based on the Flavor Profile and Texture Profile methods (Muñoz and Civille 1998). The stated benefits above the other profile methods were the inclusion of a 15-point scale, the utilization of statistics, although unspecified, and the expansion of descriptive analysis beyond food. Panelists use intensity scales that are numerical, and "absolute" or "universal". The stability of the absolute scale has not been demonstrated with data. Olabi and Lawless (2008) and Powers (1988) found contextual shifting in the Spectrum scales, even after the extensive training.

Descriptive analysis is a key methodological approach in sensory evaluation. It has been called by many professionals as the most sophisticated tool currently available to measure human perception (Bleibaum 2020). Since the introduction of descriptive analysis methods has stimulated other researchers to develop different types of descriptive methods (Delarue, Lawlor, and Rogeaux 2015). Some examples include flash profiling, free sorting, free multiple sorting, napping, polarized sensory positioning (PSP), check-all-that-apply (CATA), and ideal profiling. These methods do not involve any subject qualifying protocols or repeated trials but emphasize their speed and their flexibility vs. the "traditional" methods of Flavor Profile, Texture Profile, QDA, Spectrum, or similar types of descriptive methods. Newer methods are primarily internet-driven, eliminating the need to qualify subjects or spend time developing a language.

1.9 MULTIVARIATE ANALYSIS APPLICATIONS

Advances in statistical analysis and modeling have had a profound impact on sensory science, enhancing the precision, efficiency, and application of sensory data. Product optimization techniques fueled product innovation, beginning in earnest in the 1980s, with the increased availability of robust statistical methods (see Horsfield and Taylor 1976; Sidel and Stone 1976; Sall 1981; Stone and Sidel 1981; Fishken 1983; Moskowitz and Maier 2007; Schutz, Damrell, and Locke 1972; Schutz 1983; Schutz 1988; Sidel, Stone, and Thomas 1994; Sidel and Stone 1983).

Various multivariate analysis techniques such as principal component analysis (PCA) enable the simultaneous analysis of multiple sensory attributes and help identify patterns, relationships, and correlations within complex sensory, consumer, and physical/chemical data sets to build predictive models. Advances in experimental design methodologies, such as response surface methodology (RSM) and design of experiments (DOE), enable efficient and systematic exploration of the sensory experience, contributing to optimized and resource-efficient experimental designs (Box 1954; Cochran and Cox 1957; Taguchi and Tung 1987; Box and Draper 1987; Cohen et al. 2014).

Discriminant analysis techniques yield product groupings based on sensory attributes or other variables of interest. Such information is especially useful when the sensory data is obtained from a QDA test.

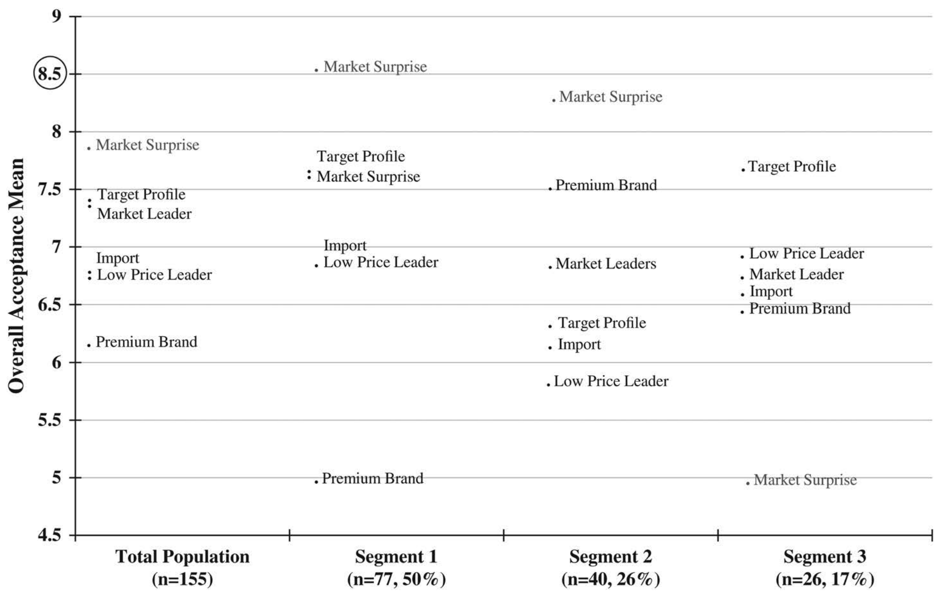


FIGURE 1.6 Overall acceptance for total population and three consumer preference segments.

Cluster analysis identifies unique groupings such as consumers with similar behaviors, for example, liking scores for products based on specific sensory attribute scores. An example of this is shown in Figure 1.6. When combined with preference data, it can identify opportunities for formulation changes as well as new product opportunities as shown in Figure 1.7.

Sensory science software has played a crucial role in advancing the field by providing tools and platforms that streamline data collection, analysis, and interpretation. By facilitating the efficient collection of sensory data, manual errors are avoided, enhancing data accuracy. Software tools also provide balanced serving designs, timed rest intervals, and more control over experimental conditions, allowing for more robust and reliable study designs. A key benefit of software is that it provides a database management processes, allowing researchers with ways to organize and store sensory data more efficiently, providing ways to more easily analyze and compare results across research studies.

These tools are helpful for sensory panel management, including tracking individual subject performance relative to the panel as a whole, detect outliers, and ensure more consistency in data collection over time, allowing researchers ways to organize and schedule sessions, manage consumer demographics, and various product measures and product ratings.

The statistical programs also provide ways to visualize data in tables, graphs, charts, and plots to aid in communicating key findings to stakeholders in a clear and concise manner. These tools have had a transformative impact on sensory science by enhancing the efficiency, accuracy, and overall capabilities of the sensory professional.

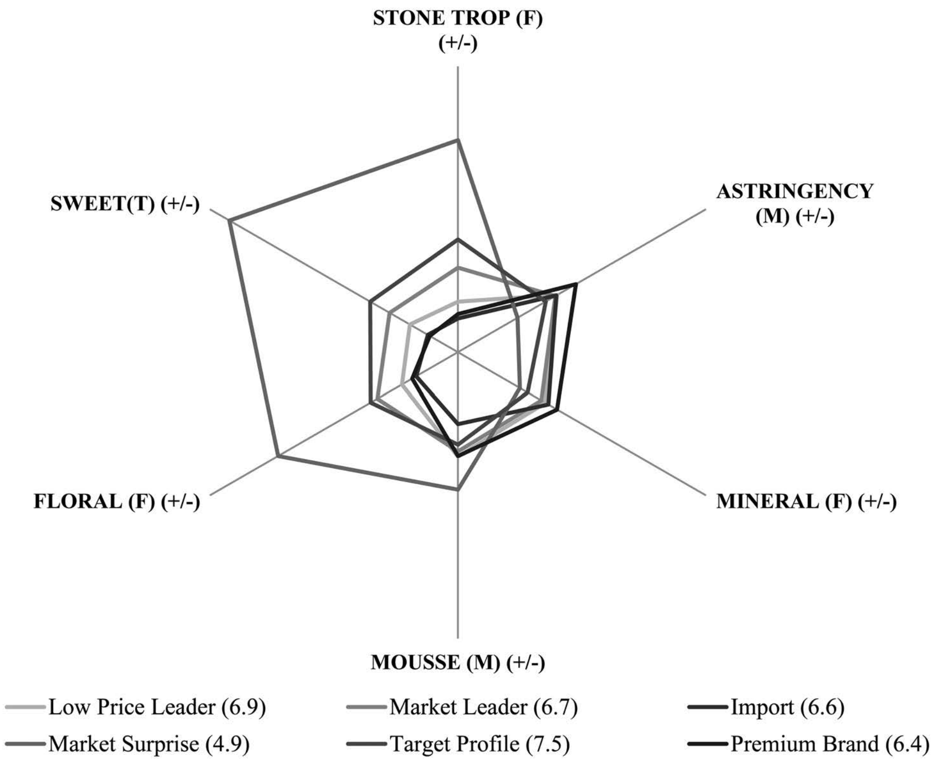


FIGURE 1.7 Important sensory attributes for a consumer preference segment.

These advancements contribute to a more robust understanding of sensory perception, allowing researchers and companies to make more informed product decisions and to optimize products for consumers.

1.10 GLOBAL REACH AND PROFESSIONAL SOCIETIES

To honor one of the pioneers in sensory science, the Rose Marie Pangborn Sensory Science Symposium was first held in Helsinki, Finland in 1992. It is now held every two years and serves as the premier international forum for researchers, professionals, and experts in sensory and consumer science. This symposium has had a significant impact on the field since its inception. It provides a platform for researchers and professionals to exchange knowledge, share research findings, and engage in discussions to facilitate networking opportunities that contribute to collaborations and partnerships in the sensory science community across different cultures and regions throughout the world. The symposium helps bridge the gap between academia and industry by highlighting emerging trends and addressing current challenges to help establish research priorities of the sensory science community. Since its inception, the Pangborn Symposium has played a pivotal role in fostering collaboration, disseminating knowledge, and influencing the direction of research and industry practices. It continues to be a cornerstone event for professionals and researchers involved in the study of sensory and consumer science.

Professional organizations and societies that focus on sensory and consumer science are active in many countries. The European Sensory Network (ESN) provides an overview of European associations, including the European Sensory Science Society (E3S). The Australian and New Zealand Association for the Sensory Sciences (ANZASS) meets in the Australasian region. In the United States, the Institute of Food Technologists (IFTs) is a prominent organization that encompasses professionals from various disciplines within the food industry, the Sensory and Consumer Science Division of IFT. The Society of Sensory Professionals (SSP), Association for Chemoreception Sciences (AChemsS), the American Society for Testing and Materials International, Committee E-18 on Sensory Evaluation, and the Sensometrics Society are a partial list of the broader sensory science community.

Participating in these societies allows sensory science professionals to stay informed about the latest research. Meetings and conferences allow for discussion and interaction, along with business applications and problem-solving from a broad array of community experts in the field.

1.11 SENSORY SCIENCE IN TODAY'S WORLD

Sensory science has evolved significantly over the years, adapting to changing technologies that enhance the precision and efficiency of sensory and consumer data. Sensory researchers are becoming more globally focused on cross-cultural studies and many of the major multinational companies employ scientists in multiple locations around the world that work together across brands. This allows us to better understand and account for individual consumer segments that represent diverse cultural backgrounds and demographics. Digital platforms including the use of virtual reality and augmented reality have gained popularity. Researchers are able to create unique testing environments that mimic cafés, restaurants, wilderness areas, and numerous other designed or natural themes. These controlled environments include other design variables such as aromatics and fragrances, tactile inputs such as mist, rain, wind, or sun. This is an area of intense research and the applications have yet to be fully realized. However, the goal is to create a controlled environment that simulates a more typical usage environment than a neutral sensory testing booth.

Sensory science plays a role in health and wellness as researchers are increasingly collaborating on global health issues such as reducing sugar, salt, and fat content in foods while ensuring that the sensory attributes meet consumer expectations. Understanding consumer desires for sustainability and how to measure the importance and impact, including eco-friendly products and upcycled foods, is another area of intense research.

Minimizing waste with a sensory quality control program and understanding alternate ingredient sources in consumer desirable products is beneficial. Sensory science is closely aligned with consumer science to optimize products for specific consumer targets. Once the products have been launched in the marketplace, sensory panels in quality control can help minimize concerning product issues, prior to sale.

There are increased educational opportunities with the establishment of academic programs and certificates in sensory science. Universities offer specialized education along with consultancies and research agencies to help meet the demand for trained professionals in the field. Sensory professionals that have access to continuous education and training programs and ones that actively engage with academic researchers will complement the traditional sensory evaluation methods that are still powerful and robust and continue to provide value to our product knowledge.

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Conventional Sensory Techniques and Industrial Practices

2

Rajesh Kumar, Oshin Sahni, and Neha Chatterjee

2.1 INTRODUCTION

Conventional sensory techniques and industrial practices are widespread and play an important role in a variety of different industries including food and beverage, pharmaceuticals, cosmetics, and manufacturing. The process requires the involvement of the five main human senses, namely sight, smell, taste, touch, and hearing (Marques et al. 2022). It is important to conduct conventional tests in the mentioned industries to facilitate multiple aspects, such as the following.

New product development: Consumer preference is vital for a product's success in the market and thus, sensory evaluation plays a crucial role in developing a new product. Conducting these consumer tests during the product development process gives companies the chance to understand the consumer preferences and fine tune the product formulations to stand out in the market (Meiselman 2013).

Quality testing: Consistency in product quality is a need for industries to maintain their standards, and sensory evaluation techniques help in detecting any defects or deviations in products that might be hard to capture through instrumental analysis. Additionally, sensory evaluation can also be used in a manufacturing setting and is

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conducted throughout the process starting at assessing raw materials, intermediate products as well as finished goods at regular intervals. This is necessary to ensure that the predetermined standards by the companies are met (Marques et al. 2022).

Troubleshooting and problem-solving: Sensory evaluation can help identify and troubleshoot issues in production processes. If a product develops an off-flavor or off-odor during manufacturing, sensory evaluation can pinpoint the source of the problem, allowing companies to rectify it promptly. Therefore, conventional sensory techniques are essential for companies to develop high-quality products that meet consumer expectations and demands (Yang and Lee 2019).

Therefore, understanding conventional sensory techniques is crucial for identifying flaws in existing products and developing new ones for consumers. It is important to look at the progression of this field over the years and to understand its need to make food palatable for millions of people. The main aim of this chapter is to explore various testing methods involved in sensory analysis and consumer research of food products. Each testing method serves a distinct purpose. For instance, sensory tests conducted for new product development differ from those performed for ingredient replacement in existing products.

2.2 BASICS OF SENSORY EVALUATION

Sensory science is a multidisciplinary field and has its roots in physiology, psychology, and neuroscience. The development of sensory science occurred in three periods – (1) 1940s–1970s, which was the first period and it sets the foundation of sensory science, (2) 1980s–1990s, which was a period of rapid expansion of the field with the formalization of the testing methods, and finally (3) 2000s–2020s, which is called the consolidation or the current period with the influence of market research and consumer preferences (Lahne 2016).

In 19th century, sensory science was linked with experimental psychology where psychologists such as Gustav Fechner, Ernst Heinrich Weber, and Wilhelm Wundt conducted initial research on sensory perception which includes Weber-Fechner law which explains the relationship between the intensity of a stimulus and the perceived magnitude. This was essential for creating a foundation for the quantitative studies conducted in sensory perception. Around the same time, the other two fields of physiology and neuroscience were advancing which led to the investigation of the physiology of audition, vision, and sensory modalities by physiologists such as Hermann von Helmholtz and Johannes Müller. This helped in understanding the role of sensory organs and receptors, neural pathways, and the way sensory information is processed. Further into the 20th century, the intersection of food science and sensory science began, and the importance of sensory evaluation is recognized to check the flavor, quality, and palatability of food products. Towards the latter half of the 20th century, many organizations such as European Sensory Science Society and Society of Sensory Professionals were founded to understand and promote sensory-related research and education. To date, sensory science is evolving, and steps are being taken to standardize sensory evaluation methods and to develop protocols and guidelines for testing and analyzing sensory data (Heymann 2019).

2.3 CONVENTIONAL SENSORY TESTING METHODS

Conventional sensory testing methods are categorized into three distinct types: discrimination, descriptive, and affective testing (Table 2.1). Discrimination testing determines whether difference exists between two or more samples or not, employing statistical analysis based on binomial distribution to assess the significance of the results. These

TABLE 2.1 Categorization of analytical and affective testing in sensory evaluation

CATEGORY	*TYPE OF TEST*	*TEST*	*APPLICATION*	*PANEL TRAINING*
Discrimination	Analytical	Pair comparison Duo-trio Triangle Tetrad A-Not-A Two-out-of-five Difference from control Ranking test	To determine if products are perceptibly different	Screened for sensory acuity, exposure to test method, training need is method dependent
Descriptive	Analytical	Flavor profile Texture profile Quantitative Descriptive Analysis (QDA®) Spectrum™ Descriptive Analysis	How do products differ on specific sensory attributes. To estimate the nature and magnitude of differences.	Screened and highly Trained highly
		Free-choice profiling	Rate the intensities of the perceived attributes	Semi-trained if performed with consumers
		Flash profiling	Order the products by the intensities of specific attributes	Semi-trained if performed with consumers
Hedonic	Affective	Hedonic rating	How are samples liked?	Screened for being the users of products, untrained
		Paired preference	Which sample is better?	
		Rank preference	Rank samples according to preference	

methods can involve both trained and untrained panelists and is primarily analytical in nature. Descriptive testing aims to elucidate the composition of a product and its sensory profile, typically involving a panel of 6–12 trained individuals who identify descriptors and rate their intensity within the product. Affective testing focuses on consumer preferences and product liking, utilizing untrained panelists who are consumers of the tested products. (Drake, Watson, and Liu 2023).

2.3.1 Discrimination Testing

Discrimination tests are analytical sensory tests and are used to tell if noticeable difference exists between two or more samples of a product. It is usually used when a company wants to make a new and improved version of a product. These tests are useful when a small difference exists between the products. If differences between the samples are big and obvious, discrimination tests aren't helpful. In that case, it's better to use other methods to measure exactly how different they are. There are different types of discrimination tests like triangle test, paired comparison, or tetrad test with different number of samples evaluated per trial and variable guessing probability as specified in Table 2.2 (Rogers 2017). These tests help companies in new product development, cost reduction, and shelf-life studies (Lawless and Heymann 2010).

TABLE 2.2 Types of discrimination tests

TEST	*TYPE OF EVALUATION*	*SAMPLES EVALUATED PER TRIAL*	*GUESSING PROBABILITY*
Paired comparison	Two samples are displayed, and panelists tell which has more attribute of interest.	2	1/2
Duo-trio	Two samples and reference are displayed; identify which sample is close to reference.	3	1/2
Triangle	Select a distinct sample from a set of three samples.	3	1/3
Tetrad	Cluster comparable samples from a set comprising four samples.	4	1/3
A-not-A	Assessors are given reference A and samples need to be assigned A or not A based on the similarity.	1	No
Two-out-of-five	Presented with 5 samples and asked to find the 2 different from the other 3.	5	1/10
Difference from control	Determine if there is a distinction between one or more encoded test samples and the control sample.	2	No
Ranking	Organize two or more samples in order of how strong a particular attribute is.	k	1/k!

Source: Adapted from Castura and Franczak (2017).

2.3.1.1 Paired comparison test

The paired comparison test is a discrimination test involving two samples also called two-product test, which helps reduce assessor fatigue (Yang and Ng 2017). Paired comparison tests come in two primary types: directional paired comparison and difference paired comparison. These tests can either be specified, focusing on a particular attribute, or unspecified, assessing overall difference. In directional paired comparison, assessors compare two samples to determine which exhibits a specific sensory attribute more prominently, without quantifying the degree of perception. This test, also known as 2-alternative forced choice (2-AFC), requires panelists to make a definitive choice. For instance, panelists might be presented with two soups varying in salt intensity and asked, "Which of the two samples tastes saltier?" Variations like 3-AFC or n-AFC involve presenting more products, enhancing sensitivity. In a 3-AFC, the chance of correctly identifying the sample with the highest attribute of interest is 33.3%.

In difference paired comparison, assessors are given two samples and asked to identify whether the samples are same or different. This test is alternatively known as a simple difference or same/different test. It is also a forced choice test where panelists must tell whether the sample pairs are same or different. In the case of two samples A and B, the panelists are presented with four pairs (AA, BB, AB, and BA) therefore, the panelists are selected as multiples of four (Adjei 2017).

In a paired comparison test, there is a 50% chance of choosing the correct answer. The null hypothesis assumes no difference between the products, with a probability of 50% or 0.5, indicating that assessors have an equal chance of randomly selecting each product if there is no genuine distinction. Typically, a minimum of seven to ten assessors is required to conduct this test. Paired comparison tests can be either forced choice or non-forced choice. In forced choice tests, assessors must select one of the two samples and indicate whether they perceive a difference or which sample exhibits a stronger attribute. In contrast, in non-forced choice tests, assessors have the option to state that they detect no difference between the samples. The AFC test is widely utilized and possesses greater sensitivity than the triangle test for detecting subtle distinctions between products. There exist two variants of paired comparison tests: one-sided and two-sided. In a one-sided comparison, a hypothesis regarding the direction of the test is predetermined, whereas in a two-sided comparison, there is no prior expectation regarding which sample will exhibit superior or inferior taste. The application of these tests extends to scenarios involving directional differences, reference testing, or assessor training (Marques et al. 2022).

This test is extensively used where there is minor difference between the samples or samples have strong lingering or carryover effect. It is a great test for items which have a strong intensity or personal care products. This test also requires less memory. It is a simple test and involves much less fatigue due to the two-product test. It is also useful if there are less samples available or if the samples are very expensive. This test helps to detect minute differences between the samples. It can also be used for screening panelists as well as for threshold determination. However, it needs a greater number of panelists or a greater number of tests to increase its sensitivity. In addition, the attribute of interest should be known before conducting this test.

2.3.1.2 Duo-trio test

The duo-trio test is also a difference test, like triangle test, that is, it tells whether a sensory difference exists between the products or not but does not tell the magnitude of difference. This test entails presenting panelists with two samples, one of which matches a reference sample provided to them. Panelists are tasked with discerning which of the two samples differs from the reference. The term "duo-trio" denotes the involvement of pairs (duo) and a third reference sample (trio). This test is characterized by its simplicity and clarity of instructions. The panelists taste the samples in a specific order and pick the one similar or close to the reference sample. The reference sample can be constant or balanced. In constant reference, the reference is kept constant and the order of serving samples is varied. For example, if the reference is R_A and there are two samples A and B, the order of presentation of samples will be R_a: A, B or R_a: B, A. In balanced reference, each product will be served as reference for an equal number of times. For example, if there are two products A and B, the order of presentation will be $R_{a:}$ A, B; R_a: B, A; R_b: A, B or $R_{b:}$ B, A. This test is useful to determine the overall product difference. However, since it is a two-product test, the probability of guessing the correct answer is 50% compared to 33.3% in triangle test, larger number of assessors will be needed to get better results.

2.3.1.3 Triangle test

The triangle test is employed to ascertain whether a perceptible difference exists between two products. Panelists are presented with three samples, two of which are identical, while the third differs in some aspect, such as taste, smell, or texture. Panelists are tasked with identifying the sample that deviates from the others. The name "triangle test" derives from the geometric arrangement of the three samples forming a triangle. This test is statistically robust because it diminishes the likelihood of panelists selecting the correct answer by mere chance. However, its effectiveness may be compromised in instances where strong residual flavors from one sample affect the perception of subsequent samples. In the triangle test, panelists are presented with three samples, two of which are similar while the third is distinct. Figure 2.1 illustrates the questionnaire utilized in the triangle test; a method commonly employed in sensory evaluation to discern

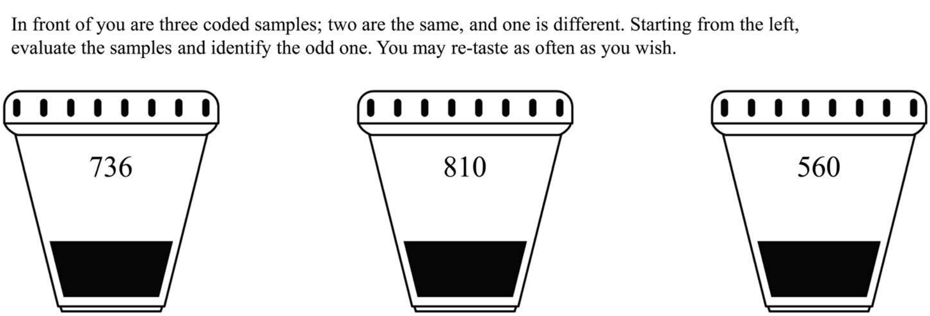

FIGURE 2.1 Questionnaire used in the triangle test.