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Faculty of Natural and Life Sciences
Department of Applied Microbiology and Food Sciences

Sensory Analysis

Course handout

3rd year Bachelor's Degree in Food Technology and Quality Control

Course code according to the training framework : UEM1

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PREFACE

This course handout has been designed as a foundational learning resource for 3rd year bachelor's degree specializing in Food Science, Agro-Food Engineering, and Quality Control. It introduces the principles and applications of sensory analysis, a scientific discipline that plays a central role in the development, evaluation, and quality assurance of food products.

Sensory analysis provides structured methods to measure, analyze, and interpret human responses to food characteristics such as appearance, aroma, taste, texture, and overall acceptability. As consumer perception increasingly drives innovation and competitiveness in the agro-food sector, mastering sensory evaluation techniques has become essential for professionals involved in product development, quality control, and regulatory compliance.

The objective of this course is to equip students with both theoretical knowledge and practical understanding of sensory analysis methodologies. Topics covered include sensory physiology, sensory evaluation methods, panel selection and training, experimental design, and basic data interpretation. Emphasis is placed on the role of sensory analysis as a complementary tool alongside physicochemical and microbiological analyses in quality management systems.

INTRODUCTION

Sensory analysis can be considered to be an interdisciplinary science that uses the sensory perception of human experts related to attribute determination thresholds, variation in experimental design of individual sensory response to measure the sensory characteristics and acceptability of a food products, and many other materials. Sensory evaluation can be used both in food producing companies and in the academic environment and the sensorialist which is the specialist in sensory evaluation and can play several roles depending on the environment in which is carry out the activity. In a food manufacturing company, a sensorialist works closely with the product developer to understand what consumers like and why, or to discover whether consumers can notice a change in an existing food product by substituting an ingredient. In the academic area, the sensorialist tries to understand how our senses work and how they respond to external stimuli (both from food and chemicals). Also, the sensorialist can work in his day-to-day work to improve the food testing methodology. The main reason why the sensory evaluation is used in addition to the physico-chemical, microbiological and nutritional evaluation of a food is to perform a complete analysis and description of it in order to establish the degree of acceptability among consumers. Even if a food product has food safety ensured by compliance with all microbiological criteria, it has a nutrient content that satisfies all the body's needs, if it is not tasty it will be rejected by consumers. Understanding "what" consumers want and "why" are two of the most significant hurdles faced by any business creating products for consumers (Figure 1).

Figure 1. Role of sensory evaluation within a food industry with well-structured departments (1).

Properly conducted sensory research experiments can provide answers to these questions and more. Thus, the role of the sensory evaluation of a food product can be explained in several directions:

➢ It helps to reduce the unknowns and risks inmaking a decision to launch a food product on themarket

➢ It ensures an efficiency of the costs of making a new product, with high acceptability to the final consumer

➢ It helps to establish order in national and international competitions

➢ And last but not least, it was found that human observers are very good measuring instruments because they can sometimes detect odours at a much lower level than can be detected with the help of instruments. Also, the instruments cannot measure the liking or the degree of pleasure(satisfaction) for a food product. In order to improve the sensory testing methodology, you must use sensory experts who can tell from the conclusions of a test, if the method is effective or not, in other words, if the results obtained help to solve a problem or require certain fine adjustments.

DEFINITION

The field of sensory evaluation grew rapidly in the second half of the twentieth century, along with the expansion of the processed food and consumer products industries. Sensory evaluation comprises a set of techniques for accurate measurement of human responses to foods and minimizes the potentially biasing effects of brand identity and other information influences on consumer perception. As such, it attempts to isolate the sensory properties of foods themselves and provides important and useful information to product developers, food scientists, and managers about the sensory characteristics of their products.

Sensory evaluation has been defined as a scientific method used to evoke, measure, analyze, and interpret those responses to products as perceived through the senses of sight, smell, touch, taste, and hearing. This definition has been accepted and endorsed by sensory evaluation committees within various professional organizations such as the Institute of Food Technologists and the American Society for Testing and Materials. The principles and practices of sensory evaluation involve each of the four activities mentioned in this definition. Consider the words “to evoke.” Sensory evaluation gives guidelines for the preparation and serving of samples under controlled conditions so that biasing factors are minimized. For example, people

in a sensory test are often placed in individual test booths so that the judgments they give are their own and do not reflect the opinions of those around them. Samples are labeled with random numbers so that people do not form judgments based upon labels, but rather on their sensory experiences. Another example is in how products may be given in different orders to each participant to help measure and counterbalance for the sequential effects of seeing one product after another. Standard procedures may be established for sample temperature, volume, and spacing in time, as needed to control unwanted variation and improve test precision.

Next, consider the words, "to measure." Sensory evaluation is a quantitative science in which numerical data are collected to establish lawful and specific relationships between product characteristics and human perception. Sensory methods draw heavily from the techniques of behavioral research in observing and quantifying human responses. For example, we can assess the proportion of times people are able to discriminate small product changes or the proportion of a group that expresses a preference for one product over another.

The third process in sensory evaluation is analysis. Proper analysis of the data is a critical part of sensory testing. Data generated from human observers are often highly variable. There are many sources of variation in human responses that cannot be completely controlled in a sensory test. Examples include the mood and motivation of the participants, their innate physiological sensitivity to sensory stimulation, and their past history and familiarity with similar products. While some screening may occur for these factors, they may be only partially controlled, and panels of humans are by their nature heterogeneous instruments for the generation of data. In order to assess whether the relationships observed between product characteristics and sensory responses are likely to be real, and not merely the result of uncontrolled variation in responses, the methods of statistics are used to analyze evaluation data. Hand-in-hand with using appropriate statistical analyses is the concern of using good experimental design, so that the variables of interest are investigated in a way that allows sensible conclusions to be drawn.

The fourth process in sensory evaluation is the interpretation of results. A sensory evaluation exercise is necessarily an experiment. In experiments, data and statistical information are only useful when interpreted in the context of hypotheses, background knowledge, and implications for decisions and actions to be taken. Conclusions must be drawn that are reasoned judgments based upon data, analyses, and results. Conclusions involve consideration of the method, the limitations of the experiment, and the background and contextual framework of the study.

I. SENSORY PERCEPTION

Sensory assessment is the evaluation of signals that a human receives through the senses of sight, hearing, taste, smell, and touch. In a way, sense organs may be viewed as detectors that help to relay information about food properties from external stimuli to the brain.

I.1 Physiology of human senses

I.1.1 Vision/Sight

Eyes is the first system of sense organs that we use when assessing the properties and quality of food. An illustration of a human eye is provided in Figure 2. The irritant or stimulus for the eyes is light. The processing of the images begins with the reflection of light from the observed object, as a result of which light passes through the cornea to the pupil. From there, light moves to the retina at the back of the eye where photoreceptors called rods and cones are agitated to convert light into nerve impulses. The rods function when light intensity is weak; cones, on the other hand, are engaged in bright light. The intensity of light striking the retina is regulated by the pupil and its ability to constrict and dilate.

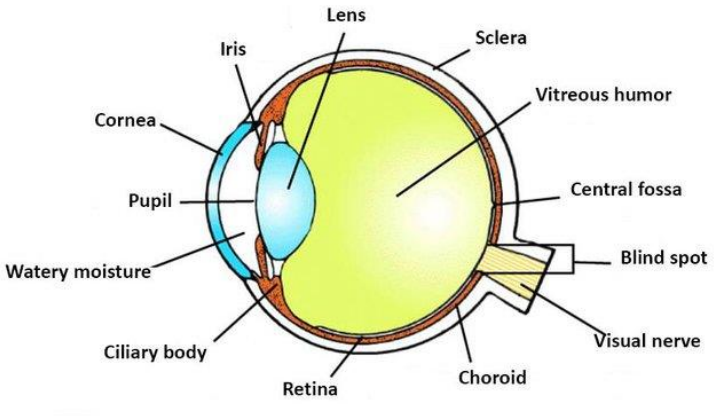

Figure 2. Cross-section of the human eye (2)

Vision perception is directly tied to other senses. For example, visual perception of food affects recognition of odor and taste, and their intensities. According to specific studies done with juice tasters, the addition of colorant to water significantly increases the use of descriptors characteristic to juice.

I.1.2 Audition/Hearing

The auditory system is one of the most important human sensory systems as a means of interpersonal communication. Acoustic signals (sound) are the stimuli of auditory system. The system itself is divided into three parts: the outer ear, the middle ear, and the inner ear (Figure 3). The outer ear consists of the visible part of the pinna (the visible part of the ear) and the auditory canal. The eardrum separates the outer ear from the middle ear. In the middle ear, three small bones are located: the hammer, the anvil, and the stapes. Inside the inner ear is the cochlea which looks like a spiral-shaped canal. The cochlea is divided into three sections, each of which is separated from the other by a membrane and contains a lymphatic fluid.

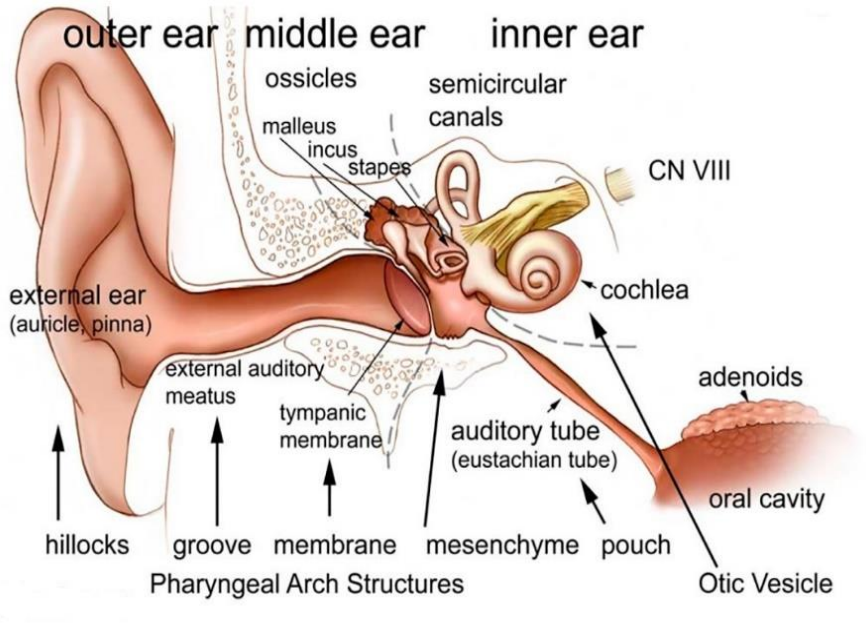

Figure 3. The cross-section of the ear (3)

When the outer part of the ear registers sound waves, they are first directed by the pinna through the auditory canal to the eardrum. The eardrum starts vibrating in turn. The hammer, anvil, and stapes of the middle ear consistently transmit vibrations through the middle ear into the inner ear where the hydraulic movement of fluids in the cochlea changes accordingly. Inside the cochlea on one of the membranes sound-receiving apparatus is located that contains hair cells that transform mechanical vibrations into signals.

I.1.3 Somatosensation/Touch

The sense of touch is a complex process of perception of external factors (e.g., mechanical influence, changes in temperature) carried out with the help of receptors located in the skin, muscles, tendons, joints, mucous membranes, and lips. The most common type of tactile receptors are free nerve endings in the surface of the skin (Figure 4). These nerve endings perform a row of different functions of thermoreceptors, pain receptors, and mechanoreceptors.

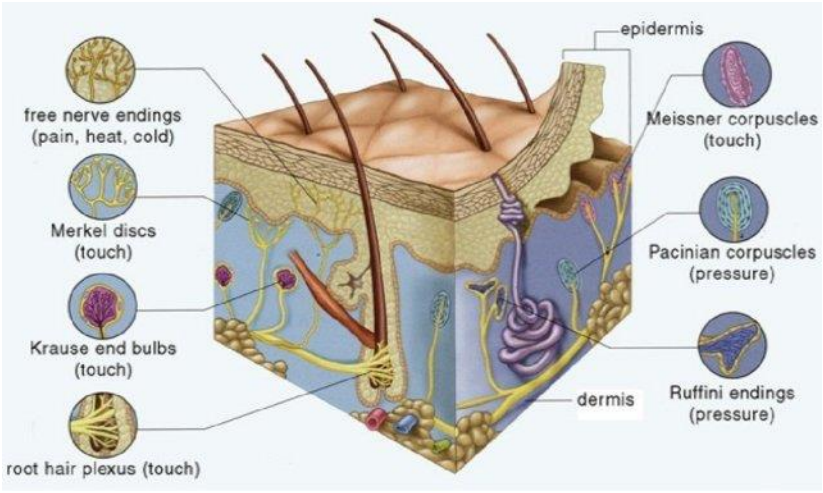

Figure 4. The cross-section of human skin (4)

Mechanoreceptors respond to touch, pressure, stretch, and vibration. The physiological basis of tactile sensation is in agitation of the receptors in the outer layers of the skin, the subsequent agitation of the nerve fibers, and the flow of information from the receptors to the central nervous system. The main receiving channel of tactile information is the spinal cord, through which the signals reach the brain.

I.1.4 Olfaction/Smell

The visible part of human nose consists of nasal bones and cartilage tissue. Before reaching the nasal cavity, the air first enters through the nostrils. The nasal septum, formed by a vertical plate of latticed bone tissue, vomer, and cartilage divides the nasal cavity into two parts. These serve as a humidifier, a heater, and a filter for incoming air. For smell perception to occur, the air containing odor-active molecules must enter the nasal cavity. Odor-active molecules dissolve on contact in the mucus covering the nasal cavity.

10-20 million olfactory sensory neurons are located in a specific small area of the nasal cavity called olfactory epithelium (Figure 5). After dissolving in the mucus, odor compounds attach

to the end of the olfactory receptors and interact with the membrane proteins. (5) Membrane proteins involved in olfactory perception are specific to olfactory receptors. There are more than 1000 kinds of receptors where each receptor cell produces one specific type of membrane protein.

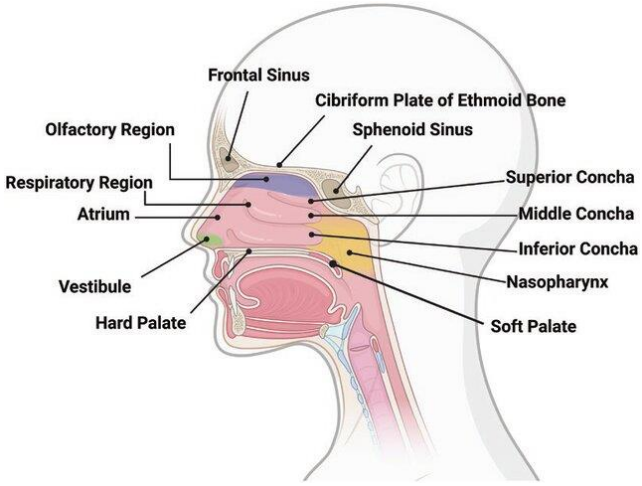

Figure 5. The nasal cavity and olfactory region (5)

Binding of molecules to the receptor proteins is selective, so that each receptor can bind only to a certain range of compounds. Likewise, each odor-active compound can bind only to a certain range of receptors. The sensitivity of the receptors to certain molecules can vary up to 1012 times or more.

Due to the anatomy of the nose, air reaches the olfactory epithelium only partially. The optimum sniffing time for a full contact is 1-2 seconds. Next comes the adaptation of the receptors to the smell, after which a pause of 5-20 seconds is recommended to restore the receptors. An additional difficulty hides in the fact that some odorants can partially block the receptors for an extended period of time reducing the ability to detect specific odors or distinguish similar odors.

The sensitivity of the sense of smell varies from person to person and depends on a number of factors such as gender, age, habits, illnesses, and trauma. Cases of complete absence of smell (anosmia) are rare but partial anosmia to certain odor compounds is common. Also, sensitivity can depend on feelings of hunger and satiety, mood, pregnancy, and menstrual cycle.

I.1.5 Gustation/Taste

The oral cavity is the first part of the digestive tract. The entrance to the oral cavity, mouth, consists of the lips, teeth, gums, tongue, and jaw. Inside the oral cavity are mechanoreceptors that respond to pressure, and muscles responsible for the chewing process. Also in the mouth

are salivary glands. Tongue plays an important role as it participates in the formation of taste sensation.

Taste sensation arises from the presence of hydrophilic molecules soluble in saliva (tastants) that interact with specific receptors in the mouth. The taste cells agglomerate into taste buds which are located both on the surface of the tongue and partially on the epithelium of the palate (Figure 6). One taste bud can contain up to 100 taste cells. The average lifespan of a taste bud is 8-12 days. New cells are continuously generated. Each taste bud has a small opening (pore) which is continuously in contact with the environment of the oral cavity. Through this pore, the tastants dissolved in saliva reach the receptors. Receptors themselves are transmembrane proteins that interact either with ions or molecules that cause taste perception.

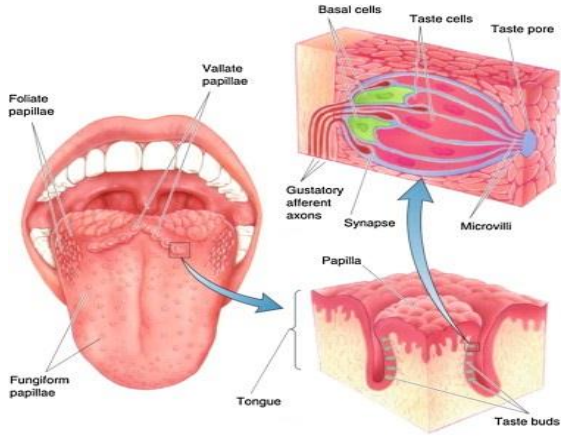

Figure 6. The structure of a taste bud (6)

Five basic tastes can be distinguished: sweet, salty, bitter, sour, and umami. Recent studies indicate that fat could be considered as an additional, sixth basic taste (6). Previously it was believed that the receptors for basic taste are located on the specific parts of the tongue: the tip of the tongue is responsible for the sweet taste; the lateral edges of the front part of the tongue – for the salty taste; the lateral edges of the back of the tongue – for the sour taste; the root of the tongue – for bitter taste. It is now widely recognized that the receptors are distributed uniformly throughout the surface of the tongue.

The perception of taste is influenced by several factors such as the concentration of the substances in the saliva, the serving temperature of the food product, duration of stimulus, and the presence of other tastants. A complete lack of sense of taste (ageusia) is very rare but there

are differences in sensitivity to certain stimuli. For example, wide variations in sensitivity to different substances causing bitter taste is quite common.

I.2 Sensory attributes

During sensory assessment, sensory attributes are addressed in the following order: appearance > odor/aroma > flavor > texture.

I.2.1 Appearance

The appearance of the food product in or out of the packaging is the main attribute used to make a rapid decision on the quality of the product or its conformity with consumer expectations. Based on that, appearance must be payed detailed attention to when assessing the samples in laboratory environment.

Appearance of a food product can be assessed in terms of shape, size, surface texture, and color (surface and cross section). Additionally for drinks, clarity and carbonations can be viewed. Characteristics of shape and size can include but are not limited to length, width, and thickness; geometric shape (e.g., square, round); distribution of filling or additives (e.g., nuts, dried fruits, vegetables). The surface texture can be dry or moist, smooth or rough, matte or shiny, soft or hard, crispy or chewy. Here, the uniformity of dusting can also be assessed. Color of the food product can be expressed in terms of value, hue, and chroma. The evenness of color can also be included when appearance is in question.

I.2.2 Odor

Odor is defined as a result of a process of volatile compounds travelling during sniffing through the nasal passage into the nasal cavity where they are perceived by the olfactory system. The process of perception of volatile compounds on the olfactory epithelium within the nasal cavity is called the orthonasal olfaction. The number of volatile compounds coming from food products depends on the serving temperature, and the nature of compounds themselves. Surface properties of the food product also play a significant role where the diffusion of volatiles through soft, wet, and porous surface is greater than through a hard, dry, and smooth surface. Some compounds are released as a result of enzymatic reactions (e.g., cutting raw onions or garlic).

I.2.3 Flavor

During oral food processing several processes happen at once to aid perception. For one, mastication of food releases volatile odor compounds that travel through nasopharyngeal passage into the nasal cavity to come in contact with olfactory epithelium. This process is called

retronasal olfaction. At the same time, tastant compounds in food dissolve in saliva to come in contact with taste receptors packed in taste buds. These tastants are perceived as sweet, sour, bitter, salty, or umami. Additional sensations tied to the sensitivity of mucous membranes of the mouth can be caused by certain chemical compounds that stimulate the nerve endings (astringency, metallic taste, spiciness, cooling sensation). The sum of aforementioned perceptions is defined as food flavor.

I.2.4 Texture

The texture can be defined as a manifestation of the mechanical, structural, and surface properties of food products. Based on that, texture can be considered as a complex sensory attribute consisting of multiple different simultaneous perceptions.

The primary perception of texture is made through the organs of sight and hearing. Terms than can be used to describe the properties of food in terms of visual perception are surface properties, homogeneity, oiliness, and moistness. Hearing organs are associated with the properties that are manifested through the sounds made when handling or chewing food (e.g., crunchiness).

The sense of touch and pressure is associated with the texture properties that characterize the structure of the food. According to structure, food products can be divided into liquids, semi-solids, and solids. Unlike liquid products, semi-solids and solids require a lot more mechanical processing in the oral cavity with the help of teeth, tongue, and jaw muscles.

I.3 Factors affecting sensory perception

I.3.1 Thresholds

Threshold can be defined as a limit to sensory perception. Thresholds are applicable in both odor and taste and are divided into four categories: absolute threshold, recognition threshold, differential threshold, and terminal threshold. Absolute threshold is the lowest concentration of a stimulus (e.g., volatile compound, or tastant) that can be detected. Recognition threshold is the concentration of a stimulus at which the stimulus is recognized and described. Differential threshold is the increase in concentration of stimulus that can be detected. Terminal threshold is the concentration above which a further increase in concentration can no longer be detected (Figure 7). Above this, pain often occurs.

The assessor's threshold is the concentration of any given compound where the sensations caused by the compound are detected 50% of the time.

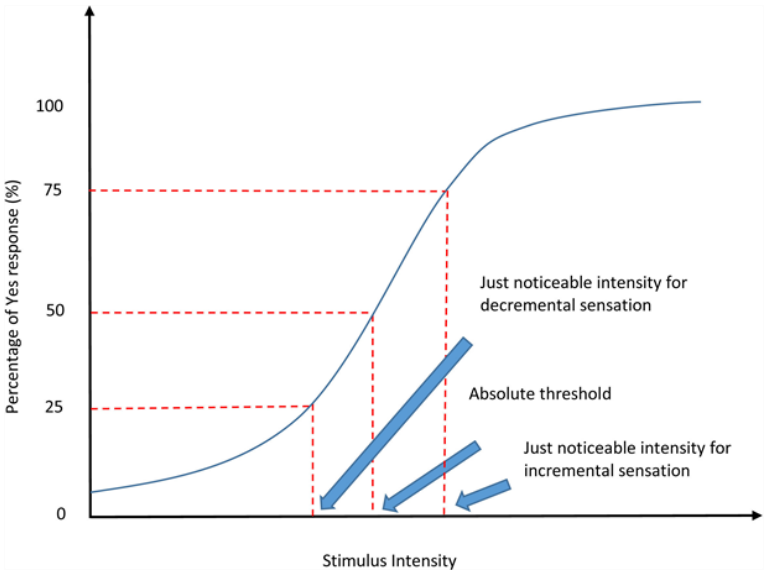

Figure 7. Absolute threshold obtained from psychometric function. (7)

Thresholds, however, cannot be considered a constant and often fluctuate depending on a number of factors. For example, thresholds can be affected by lack of focus, mood swings, changes in biorhythm, feelings of hunger and satiety, etc.

I.3.2 Physiological factors

First and foremost, overall physical and health condition of panel members should be taken into account. The assessors should be excluded from the session when their health is compromised (e.g., common cold, flu, infections), or they suffer from emotional distress and heavy pressure of work.

Smokers should not smoke up to one hour before assessment session. Coffee should also be forbidden up to one hour before analysis. Two hours should pass after a large meal before engaging in sensory assessment.

Other physiological factors at play that might affect panel performance include adaptation; enhancement, synergy or suppression. Adaptation forms as a result of a prolonged exposure to a stimulus where decrease in sensitivity can be observed. Enhancement, synergy or suppression of a stimulus can occur when more than one stimulus are present and interact with each other. As a result of the interaction, one stimulus might be enhanced by the presence of the others (=enhancement); multiple stimuli can be create a sensation greater in intensity than the sum of sensations caused by the stimuli independently (=synergy); one stimulus is suppressed by the presence of others (=suppression).

I.3.3 Psychological factors

The psychological factors that affect sensory assessment by a panel include:

- Expectation error

Expectation errors might occur when too much information about the objectives or samples is given prior or during the analysis. Unnecessary information might trigger certain expectations that indirectly warp panelist's judgement. Instead, samples should be coded and randomized; the amount of information disclosed should be minimal and just enough to fulfil test's objectives.

- Habituation error

When similar samples are presented on a regular basis, habituation error occurs where the panelists feel inclined to assign similar scores irrespective of actual differences that might occur. Habituation error is more common in quality control and can be avoided by varying samples presented to the panel or by introducing from time to time intentionally altered samples.

- Suggestion and distraction errors

Unnecessary noises or comments made during the analysis might affect focus and, therefore, judgement of the panel. To avoid this error the environment should be quiet and free of distractions; unnecessary banter within the panel should be discouraged; when possible, sensory booths should be used.

- Stimulus and logical errors

When irrelevant properties affect the judgement of the panelists (e.g., color) stimulus error occurs. When the irrelevant properties can also be tied to certain attributes (for example, deeper colored samples are viewed as more intense either in odor or flavor) logical error occurs. To avoid these errors, presented samples should be as uniform as possible or the irrelevant differences masked (colored sniffing glasses, colored lighting, nose clips, etc.).

- Order error

The judgement of one sample can be influenced by the samples that were presented before it. Additionally, the samples that are presented first tend to get higher scores of intensities. To avoid the error, samples can be randomized, additionally balanced, or a "blank" sample of the same product category can be presented first to the panelists.

- Halo effect error

Halo effect error occurs when the perception of one attribute subconsciously affects the perception of others. For example, the sweetest sample can be viewed as the stickiest. The error is the most common in untrained assessors. To avoid the error, it is advised to use a panel of trained assessors.

- Contrast effect error

If the difference between two samples in a line-up is too striking, the panelists might feel inclined to exaggerate those differences. On the other hand, if similar samples are presented in a group of highly different samples, their similarity might be exaggerated. To avoid the error, the order of presentation of the samples can be balanced. Additionally, if possible, samples producing the unnecessary contrast in a line-up should be excluded from the test.

- Central tendency error

When scales are used for assessment to quantify the differences between the samples more often than not panelists tend to avoid the extreme scores (the lowest and the highest) and work in the middle of the scale. To avoid the error, the panelist should be trained and encouraged to use the scale in its entirety. Additionally, the scale itself should be large enough to accommodate significant differences between the samples.

- Lack of motivation

The degree of motivation of panel members will affect how focused and consistent will they be in their judgements. Lack of motivation should be especially addressed when a sensory panel consists out of employees that perform sensory analysis in addition to other work responsibilities. To raise motivation in panel members, regular feedback on the performance should be given. When possible, the importance of panel activities should be emphasized.

II. OPERATING PROCEDURES

The objectives of the analysis should be defined early on to ensure the success and relevance of the results. The correctly assessed objectives and expected results determine the rest of the experimental design and efficient use of resources. The following question can help to define the objectives of the analysis:

- Are products different?
- How great/intense/significant is the difference between the products?
- What are the sensory properties of the product?
- What sensory properties are significant?
- How sensory properties change with time/processing/reformulation/packaging? …etc

II.1 Testing areas

Specific testing areas are required for sensory evaluation to ensure controlled conditions and reduce the external factors that may affect the judgement of the sensory panel members. The rooms designated specifically for sensory analysis should be located close to the facilities where preparation of the samples for the analysis is going to take place.

The temperature and humidity levels of the testing area should be controlled and monitored at a constant rate. The recommended temperature is 22-24°C; relative humidity – 45-55%. Air circulation and ventilation systems should be in place.

The testing area should be free of odors. A slight positive pressure can be maintained to prevent the inflow of air from outside (Figure 8). The construction materials should be free of specific odor and easy to clean if needed. The use of fabrics should be limited. The assessors are not allowed to use perfume/cologne or perfumed soap the day of the assessment.

Testing environment should be free of noise and other distractions. The color of the walls and furniture should be as neutral as possible (white, beige, and light grey colors are recommended). The lighting should be uniform; the intensity of light source should be controlled and dimmed if necessary. Colored lights can be used to mask the color differences of the samples if required by the aims of the analysis.

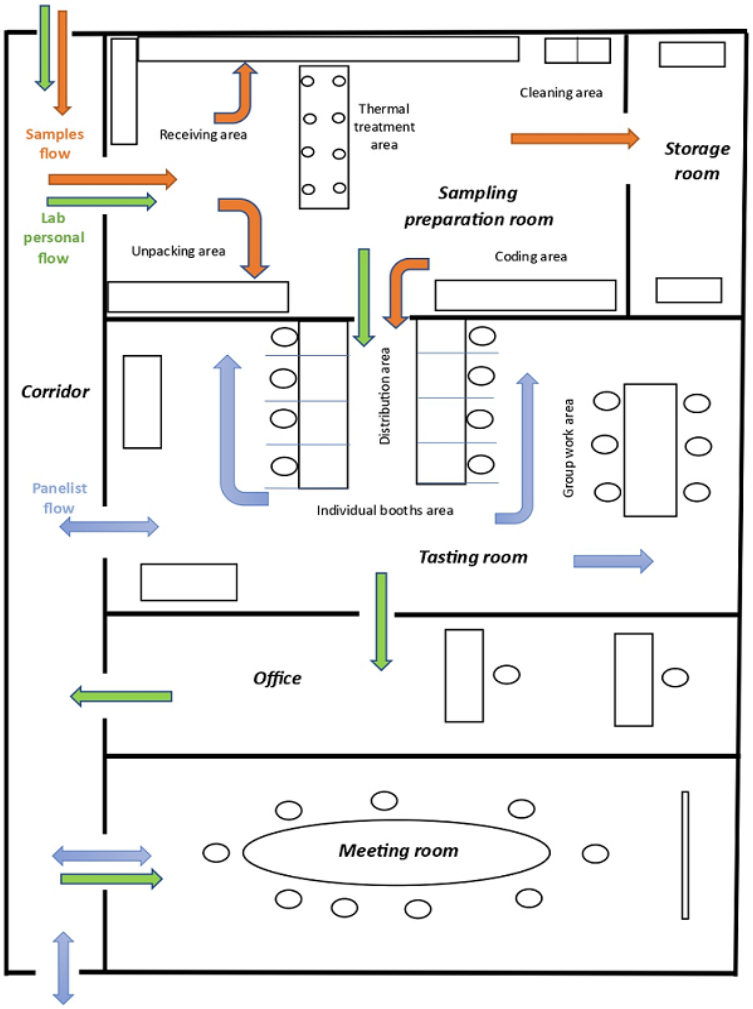

Figure 8. Spaces of the sensory analysis laboratory (8)

To limit communication and distraction, independent judgement of the panelists can be promoted by building testing booths. The number of booths in the testing area largely depends on available free space. It is, however, recommended for a testing room to have enough space to fit 10-12 people with additional space available for unrestricted movement. A separate table with enough chairs should be available for group discussions.

II.2 Modalities related to the panel

II.2.1 The selection of sensory panel members

The pool of candidates for the sensory panel can be picked either within the company (Research & Development team members, office staff, or line workers) or from a number of volunteers outside the company. Having an in-house panel comprised out of workers has certain advantages since the members are then more familiar with the assessed products. However, if the company personnel cannot be made available for regular sensory assessments at least for 10 minutes at a time, the panel has to be assembled and trained from volunteers.

The potential candidates should be in good health (no allergies; no signs of color blindness, anosmia, or ageusia), possess availability, willingness, and motivation to participate in the assessment sessions on a regular basis and able to perform the tasks according to given instructions. Strong aversions to certain foods should be determined in pre-screening sessions; potential panelists should be available to taste a wide range of products. Assessors may be required to make a consensus decisions based on the discussions; therefore, extremely dominant and very passive or indecisive personalities should be avoided.

II.2.2 Sensory panel size

A number of assessor involved in the sensory panel should be large enough to produce statistically significant results. In the sensory panel that is too small, the results are too dependent on the individual judgement of the assessor. However, even a small panel of highly trained assessors will most likely provide considerably significant results. In some cases, the number of panel members depends on the nature of sensory assessment method. Due to workforce turnover (illness, change of employer), the size of the panel should be maintained constant and new members trained to fill the gap.

II.3 Modalities related to the sample

II.3.1 Number of samples

The number of samples presented to the panelists in a single session is limited by several factors. The analysis that involves the assessment of visual attributes allows considerably more samples than the analysis of odor and/or flavor due to odor and taste receptors being easily fatigued. Furthermore, if the number of attributes assessed in the one sitting is extensive, fewer samples should be given. Experienced panelists are able to produce reliable judgements faster with fewer sniffs, sips, or tastes of the product, making it possible to go through more samples in one session.

In some cases, the number of samples presented to the panelists is strictly defined by the nature of sensory assessment method.

II.3.2 Sample preparation and presentation

Sample preparation should be done by following good laboratory and/or good hygiene practice. The portion sizes should be enough for sensory assessment. Too much of the sample will encourage assessors to take larger bites or sips causing sensory fatigue early on.

There’s a number of different sample presentation techniques used in sensory analysis. Most frequently used are sequential monadic presentation and simultaneous presentation. In

sequential monadic presentation, the samples are presented to panelists one by one. Samples are assessed separately in a timely manner. This order of presentation is thought to be the most appropriate if samples, for example, are temperature sensitive. In simultaneous presentation, all samples are given to the panelists at once. This technique of sample presentation is a common practice in discrimination tests and ranking of the products based on specific attribute.

II.3.3 Blind tasting and randomization

The assessment of samples should proceed in blind tasting conditions. In blind tasting, no background information is provided to the panelists about the samples and their source. Unnecessary information might affect the objectiveness of panel judgement and result in unreliable data.

When multiple samples are presented to the panel, it is important to use randomization within the order of sample presentation. This way, the place of any specific sample in a line- up will always be different and reduce order effects. Additionally, the order in which the samples are received can be different for each assessor to maximize the positive effects of this approach.

II.3.4 Number of parallels

The parallels in sensory assessment are defined by repeated judgements on a sample. The parallels are used to increase the reliability and statistical significance of the results. The parallels for the samples can be included in the same assessment session or done separately. The number of parallels largely depends on the sensory method used to achieve the objectives. In general, the methods used to confirm the existence of a difference between the samples favor the use of a larger panel with fewer parallels. The methods where the properties of the samples need to be described and scored require multiple independent judgements made by a trained panel. Two to three parallels are considered to be optimal.

II.3.5 Palate cleansing

To avoid the overstimulation of senses and carry-over effects, the palate should be cleansed between the samples. Still mineral water is widely used as a palate cleanser in sensory assessment; the oral cavity should be thoroughly rinsed to remove most of the residual taste of a sample before moving on to the next one. In some specific instances mineral water won't be enough to provide sufficient palate cleansing. These instances include oily, spicy, and highly astringent foods. For oily products, slices of apple and pear can be recommended as an appropriate palate cleanser; for spicy foods – milk or yogurt; for astringent foods – melon.

II.4 Classes of test methods

The current sensory evaluation methods comprise a set of measurement techniques with established track records of use in industry and academic research. Much of what we consider standard procedures comes from pitfalls and problems encountered in the practical experience of sensory specialists over the last 70 years of food and consumer product research, and this experience is considerable. The primary concern of any sensory evaluation specialist is to insure that the test method is appropriate to answer the questions being asked about the product in the test. For this reason, tests are usually classified according to their primary purpose and most valid use. Three types of sensory testing are commonly used, each with a different goal and each using participants selected using different criteria. A summary of the three main types of testing is given in Table 1.

Table 1. Classification of test methods in sensory evaluation (9)

Class	Question of interest	Type of test	Panelist characteristics
Discrimination	Are products perceptibly different in any way	Analytic	Screened for sensory acuity, oriented to test method, sometimes trained
Descriptive	How do products differ in specific sensory characteristics	Analytic	Screened for sensory acuity and motivation, trained or highly trained
Affective	How well are products liked or which products are preferred	Hedonic	Screened for products, untrained

II.4.1 Difference Testing

The simplest sensory tests merely attempt to answer whether any perceptible difference exists between two types of products. These are the discrimination tests or simple difference testing procedures. Analysis is usually based on the statistics of frequencies and proportions (counting right and wrong answers). From the test results, we infer differences based on the proportions of persons who are able to choose a test product correctly from among a set of similar or control products. Ability to discriminate differences would be inferred from consistent correct choices above the level expected by chance. In breweries, this test served primarily as a means to screen

judges for beer evaluation, to insure that they possessed sufficient discrimination abilities. Simple difference tests have proven very useful in application and are in widespread use today. Typically a discrimination test will be conducted with 25–40 participants who have been screened for their sensory acuity to common product differences and who are familiar with the test procedures. This generally provides an adequate sample size for documenting clear sensory differences. Often a replicate test is performed while the respondents are present in the sensory test facility. In part, the popularity of these tests is due to the simplicity of data analysis. Statistical tables derived from the binomial distribution give the minimum number of correct responses needed to conclude statistical significance as a function of the number of participants. Thus a sensory technician merely needs to count answers and refer to a table to give a simple statistical conclusion, and results can be easily and quickly reported.

II.4.2 Descriptive Analyses

The second major class of sensory test methods is those that quantify the perceived intensities of the sensory characteristics of a product. These procedures are known as descriptive analyses. This technique, the Texture Profile method, used a fixed set of force-related and shape-related attributes to characterize the rheological and tactile properties of foods and how these changed over time with mastication. These characteristics have parallels in the physical evaluation of food breakdown or flow. For example, perceived hardness is related to the physical force required to penetrate a sample. Perceived thickness of a fluid or semisolid is related in part to physical viscosity. Texture profile panelists were also trained to recognize specific intensity points along each scale, using standard products or formulated pseudo-foods for calibration. Descriptive analysis has proven to be the most comprehensive and informative sensory evaluation tool. It is applicable to the characterization of a wide variety of product changes and research questions in food product development. The information can be related to consumer acceptance information and to instrumental measures by means of statistical techniques such as regression and correlation.

II.4.3 Affective Testing

The third major class of sensory tests is those that attempt to quantify the degree of liking or disliking of a product, called hedonic or affective test methods. The most straightforward approach to this problem is to offer people a choice among alternative products and see if there is a clear preference from the majority of respondents. The problem with choice tests is that they are not very informative about the magnitude of liking or disliking from respondents. An historical landmark in this class of tests was the hedonic scale developed at the U.S. Army Food

and Container Institute in the late 1940s. This method provided a balanced 9-point scale for liking with a centered neutral category and attempted to produce scale point labels with adverbs that represented psychologically equal steps or changes in hedonic tone. In other words, it was a scale with ruler-like properties whose equal intervals would be amenable to statistical analysis. An example of the 9-point scale is shown in Figure 9.

Typically, a hedonic test today would involve a sample of 75–150 consumers who were regular users of the product. The test would involve several alternative versions of the product and be conducted in some central location or sensory test facility.

9-Point Hedonic Scale	
9	Like Extremely
8	Like Very Much
7	Like Moderately
6	Like Slightly
5	Neither Like nor Dislike
4	Dislike Slightly
3	Dislike Moderately
2	Dislike Very Much
1	Dislike Extremely

Figure 9. The 9-point hedonic scale used to assess liking and disliking. (9)

The larger panel size of an affective test arises due to the high variability of individual preferences and thus a need to compensate with increased numbers of people to insure statistical power and test sensitivity. This also provides an opportunity to look for segments of people who may like different styles of a product, for example, different colors or flavors. It may also provide an opportunity to probe for diagnostic information concerning the reasons for liking or disliking a product.

III. SENSORY ANALYSIS TESTS

III.1 Triangle test

III.1.1 Scope

This test specifies a procedure for determining whether a perceptible sensory difference or similarity exists between samples of two products. The method is a forced-choice procedure. The method is applicable whether a difference exists in a single sensory attribute or in several attributes.

The method is statistically more efficient than the duo-trio test, but has limited use with products that exhibit strong carryover and/or lingering flavours.

The method is applicable even when the nature of the difference is unknown [i.e. it determines neither the size nor the direction of difference between samples, nor is there any indication of the attribute(s) responsible for the difference]. The method is applicable only if the products are homogeneous.

The method is effective for:

a) determining that:

1) either a perceptible difference results (triangle testing for difference);

2) a perceptible difference does not result (triangle testing for similarity), when, for example, a change is made in ingredients, processing, packaging, handling or storage;

b) selecting, training and monitoring assessors.

III.1.2 Principle

The number of assessors is chosen based on the sensitivity desired for the test. Assessors receive a set of three samples (i.e. a triad) and are informed that two of the samples are the same and that one is different. The assessors report which sample they believe to be different, even if the selection is based only on a guess.

The number of correct responses is counted, and the significance is determined by reference to a statistical table or an applicable computer program.

III.1.3 General test conditions and requirements

- Prepare the samples out of sight of the assessors and in an identical manner (e.g. same apparatus, same vessels, same quantities of product).
- Assessors shall not be able to identify the samples from the way in which they are presented. For example, in a taste test, avoid any differences in appearance. Mask any irrelevant color differences using light filters and/or subdued illumination.
- Code the test samples in a uniform manner, preferably using three-digit numbers, chosen at random for each test. Each triad is composed of three samples, each with a different code. Preferably, different codes should be used for each assessor during a session. However, the same three codes may be used for all assessors within a test, provided that each code is used only once per assessor during a test session (e.g. if several triangle tests on different products are being conducted in the same session).
- It is preferable to present the samples under the conditions at which the product is generally used (e.g. in a taste test, present the samples at the temperature at which the product is generally consumed). The serving conditions of the three samples in each triad shall be identical (e.g. in a taste test, the three samples shall be served at the same temperature), just as that of all the other samples in a series of tests on a given type of product.
- The size, quantity or volume presented shall be identical for the three samples in each triad, just as that of all the other samples in a series of tests on a given type of product. The size, quantity or volume to be evaluated may be imposed. If it is not, the assessors should be told to take sizes, quantities or volumes that are always similar whatever the sample.
- In a taste test, the assessors shall be told whether or not they are to swallow the samples or whether they are free to do as they please. In this latter case, they shall be requested to proceed in the same manner for all the samples.
- During the test sessions, avoid giving information about product identity, expected treatment effects, or individual performance until all testing is completed. The only necessary information for the assessor is the nature of the product to be tested and the task to be performed.

III.1.4 Number of assessors

The number of assessors is chosen so as to obtain the sensitivity required for the test. Using large numbers of assessors increases the likelihood of detecting small differences between the products. However, in practice, the number of assessors is often determined by material conditions (e.g. duration of the experiment, number of available assessors, quantity of product). When testing for a difference, typical numbers of assessors are between 24 and 30. When testing for no meaningful difference (i.e. similarity), twice as many assessors (i.e. approximately 60) are needed for equivalent sensitivity.

Avoid replicate evaluations by the same assessor whenever possible. However, if replicate evaluations are needed to produce a sufficient number of total evaluations, every effort should be made to have each assessor perform the same number of replicate evaluations. For example, if only 10 assessors are available, have each assessor evaluate 3 triads to obtain a total of 30 evaluations.

NOTE. Treating three evaluations performed by 10 assessors as 30 independent evaluations is not valid when testing for similarity using Table 3. However, the test for difference using Table 2 is valid even when replicate evaluations are performed.

III.1.5 Procedure

- Prepare worksheets and scoresheets in advance of the test so as to utilize an equal number of the six possible sequences of two products, A and B:

ABB	AAB	ABA
BAA	BBA	BAB

- Distribute these at random in groups of six among the assessors (i.e. use each sequence once among the first group of six assessors; use each sequence once again among the next group of six assessors, etc.). This will minimize the imbalance that results if the total number of assessors is not a multiple of six.
- Present the three samples of each triad simultaneously if possible, following the same spatial arrangement for each assessor (e.g. on a line to be sampled always from left to right, in a triangular array). Within the triad, assessors are generally allowed to make repeated evaluations of each sample as desired (if, of course, the nature of the product allows for repeated evaluations).
- Instruct the assessors to evaluate the samples in the order in which they were presented. Inform the assessors that two of the samples are the same and that one is different. Each

assessor shall then indicate which one of the three samples is different from the other two.

- The triangle test is a forced-choice procedure. Assessors are not allowed the option of reporting "no difference". An assessor who detects no difference between the samples should be instructed to randomly select one of the samples and to indicate that the selection was only a guess in the comments section of the scoresheet. The assessor has one chance out of three of giving the correct answer randomly.
- The assessor shall not go back to any samples from previous triads or change the verdict on any previous test. If an assessor is to carry out more than one test in a session, it is imperative that the assessor shall not be able to change their response once given. For example, collect the completed scoresheet and unused samples prior to serving the subsequent triad or do not allow the assessor to return to an earlier answer screen once a response is confirmed.
- Do not ask questions about preference, acceptance or degree of difference after the initial selection of the odd sample. The selection the assessor has just made may bias the reply to any additional questions. Responses to such questions may be obtained through separate tests for preference, acceptance, degree of difference, etc. A comment section asking why the choice was made may be included for the assessor's remarks.

III.1.6 Analysis and interpretation of results

✓ **When testing for a difference**

Table 2 is used to analyse the data obtained from a triangle test. If the number of correct responses is greater than or equal to the number given in Table 2 (corresponding to the number of assessors and the α-risk level chosen for the test), conclude that a perceptible difference exists between the samples.

Table 2. Minimum number of correct responses needed to conclude that a perceptible difference exists based on a triangle test (10)

n	α					n	α				
	0,20	0,10	0,05	0,01	0,001		0,20	0,10	0,05	0,01	0,001
6	5	6	6	—	—	26	16	17	18	20	22
7	6	6	7	7	—	27	17	18	19	20	22
8	6	7	7	8	—	28	17	18	19	21	23
9	7	7	8	9	—	29	18	19	20	22	24
10	7	8	9	10	10	30	18	20	20	22	24
11	8	9	9	10	11	32	19	21	22	24	26
12	8	9	10	11	12	36	22	23	24	26	28
13	9	10	10	12	13	40	24	25	26	28	31
14	10	10	11	12	13	44	26	27	28	31	33
15	10	11	12	13	14	48	28	29	31	33	36
16	11	12	12	14	15	52	30	32	33	35	38
17	11	12	13	14	16	56	32	34	35	38	40
18	12	13	13	15	16	60	34	36	37	40	43
19	12	13	14	15	17	64	36	38	40	42	45
20	13	14	15	16	18	68	38	40	42	45	48
21	13	14	15	17	18	72	41	42	44	47	50
22	13	14	15	17	19	76	43	45	46	49	52
23	15	16	16	18	20	80	45	47	48	51	55
24	15	16	17	19	20	84	47	49	51	54	57
25	16	17	18	19	21	88	49	51	53	56	59

NOTE 1 Values in the table are exact because they are based on the binomial distribution. For values of n not in the table, compute approximate values for the missing entries based on the normal approximation to the binomial as follows:

minimum number of responses (x) = nearest whole number greater than

$$x = (n/2) + z\sqrt{n/4}$$

where z varies with the significance level as follows: 0,84 for α = 0,20; 1,28 for α = 0,10; 1,64 for α = 0,05; 2,33 for α = 0,01; 3,09 for α = 0,001.

NOTE 2 Values of n < 24 are usually not recommended for a duo-trio test for a difference.

✓ **When testing for similarity**

- "similar" does not mean "identical". Rather, "similar" means that the two products are sufficiently alike to be used interchangeably. It is not possible to prove that two products are identical. However, it can be demonstrated that any difference that does exist between two products is so small as to have no practical significance.
- Use Table 3 to analyse the data obtained from a triangle test. If the number of correct responses is less than or equal to the number given in Table 3 (corresponding to the number of assessors, the β-risk level and the value of pd chosen for the test), conclude that no meaningful difference exists between the samples.

Table 3 — Maximum number of correct responses needed to conclude that two samples are similar, based on a triangle test (10)

n	β	p_d					n	β	p_d				
		10 %	20 %	30 %	40 %	50 %			10 %	20 %	30 %	40 %	50 %
18	0,001	0	1	2	3	5	66	0,001	14	18	22	26	31
	0,01	2	3	4	5	6		0,01	16	20	25	29	34
	0,05	3	4	5	6	8		0,05	19	23	28	32	37
	0,10	4	5	6	7	8		0,10	20	25	29	33	38
	0,20	4	6	7	8	9		0,20	22	26	31	35	40
24	0,001	2	3	4	6	8	72	0,001	15	20	24	29	34
	0,01	3	5	6	8	9		0,01	18	23	28	32	38
	0,05	5	6	8	9	11		0,05	21	26	30	35	40
	0,10	6	7	9	10	12		0,10	22	27	32	37	42
	0,20	7	8	10	11	13		0,20	24	29	34	39	44
30	0,001	3	5	7	9	11	78	0,001	17	22	27	32	38
	0,01	5	7	9	11	13		0,01	20	25	30	36	41
	0,05	7	9	11	13	15		0,05	23	28	33	39	44
	0,10	8	10	11	14	16		0,10	25	30	35	40	46
	0,20	9	11	13	15	17		0,20	27	32	37	42	48
36	0,001	5	7	9	11	14	84	0,001	19	24	30	35	41
	0,01	7	9	11	14	16		0,01	22	28	33	39	45
	0,05	9	11	13	16	18		0,05	25	31	36	42	48
	0,10	10	12	14	17	19		0,10	27	32	38	44	49
	0,20	11	13	16	18	21		0,20	29	34	40	46	51
42	0,001	6	9	11	14	17	90	0,001	21	27	32	38	45
	0,01	9	11	14	17	20		0,01	24	30	36	42	48
	0,05	11	13	16	19	22		0,05	27	33	39	45	52
	0,10	12	14	17	20	23		0,10	29	35	41	47	53
	0,20	13	16	19	22	24		0,20	31	37	43	49	55
48	0,001	8	11	14	17	21	96	0,001	23	29	35	42	48
	0,01	11	13	17	20	23		0,01	26	33	39	45	52
	0,05	13	16	19	22	26		0,05	30	36	42	49	55
	0,10	14	17	20	23	27		0,10	31	38	44	50	57
	0,20	15	18	22	25	28		0,20	33	40	46	53	59
54	0,001	10	13	17	20	24	102	0,001	25	31	38	45	52
	0,01	12	16	19	23	27		0,01	28	35	42	49	56
	0,05	15	18	22	25	29		0,05	32	38	45	52	59
	0,10	16	20	23	27	31		0,10	33	40	47	54	61
	0,20	18	21	25	28	32		0,20	36	42	49	56	63
60	0,001	12	15	19	23	27	108	0,001	27	34	41	48	55
	0,01	14	18	22	26	30		0,01	31	37	45	52	59
	0,05	17	21	25	29	33		0,05	34	41	48	55	63
	0,10	18	22	26	30	34		0,10	36	43	50	57	65
	0,20	20	24	28	32	36		0,20	38	45	52	60	67

NOTE 1 Values in the table are exact because they are based on the binomial distribution. For values of n not in the table, compute the 100(1–β) % upper confidence limit for p_d based on the normal approximation to the binomial as:

$$[1{,}5(x/n) - 0{,}5] + 1{,}5\, z_\beta \sqrt{(nx - x^2)/n^3}$$

where

x is the number of correct answers; n is the number of assessors; z_β varies as follows: 0,84 for $\beta = 0{,}20$; 1,28 for $\beta = 0{,}10$; 1,64 for $\beta = 0{,}05$; 2,33 for $\beta = 0{,}01$; 3,09 for $\beta = 0{,}001$.

If the computed value is less than the selected limit for p_d, then declare the samples similar at the β level of significance.

NOTE 2 Values of $n < 30$ are usually not recommended for a triangle test for similarity.

III.2 Duo-trio test

III.2.1 Scope

This test specifies a procedure for determining whether a perceptible sensory difference or similarity exists between samples of two products. The method is a forced-choice procedure. The method is applicable whether a difference exists in a single sensory attribute or in several attributes.

The method is statistically less efficient than the triangle test but is easier to perform by the assessors. It is applicable even when the nature of the difference is unknown (i.e. it determines neither the size nor the direction of difference between samples, nor is there any indication of the attribute(s) responsible for the difference). The method is applicable only if the products are fairly homogeneous. The method is effective for :

a) determining that 1)either a perceptible difference results (duo-trio testing for difference), or

2) a perceptible difference does not result (duo-trio testing for similarity) when, for example, a change is made in ingredients, processing, packaging, handling or storage.

b) for selecting, training and monitoring assessors.

Two forms of the method are described:

— the constant-reference technique, used when one product is familiar to the assessors (e.g. a sample from regular production);

— the balanced-reference technique, used when one product is not more familiar than the other.

III.2.2 Principle

The number of assessors is chosen based on the sensitivity desired for the test. Assessors receive a set of three samples (i.e. a triad), one sample of which is labelled as a reference and the other two samples have different codes. The assessors are informed that one of the coded samples is the same as the reference and that one is different. Based on their training and the instructions given prior to the test, the assessors report either which of the coded samples they believe to be same as the reference, or which of the coded samples they believe to be different from the reference. The number of correct responses is counted and the significance is determined by reference to a statistical table.

III.2.3 General test conditions and requirements

See the same chapter regarding the triangular test.

III.2.4 Procedure

1 If the product is familiar to the assessors (e.g. a control sample from the production line), use the constant reference technique. If neither product is more familiar than the other, use the balanced reference technique

a) Constant-reference technique:

Prepare worksheets and scoresheets in advance of the test so as to utilize an equal number of the two possible sequences of two products, A and B:

A-REF AB A-REF BA

Distribute these at random in groups of two among the assessors (i.e. use each sequence once among the first two assessors; use each sequence once again among the next two assessors, etc.) This will minimize the imbalance that results if the total number of assessors is not an even number.

b) Balanced-reference technique:

Prepare worksheets and scoresheets in advance of the

test so as to utilize an equal number of the four possible sequences of two products, A and B:

A-REF AB A-REF BA

B-REF AB B-REF BA

where the first two triads contain product A as the reference (i.e. A-REF) and the last two triads contain product B as the reference (i.e. B-REF). Distribute these at random in groups of four among the assessors.

III.2.5 Analysis and interpretation of results

- ✓ **When testing for a difference**

Use Table 4 to analyse the data obtained from a duo-trio test. If the number of correct responses is greater than or equal to the number given in Table 4 (corresponding to the number of assessors and the α-risk level chosen for the test), conclude that a perceptible difference exists between the samples

Table 4. Minimum number of correct responses needed to conclude that a perceptible difference exists based a duo-trio test (11)

n	α					n	α				
	0,20	0,10	0,05	0,01	0,001		0,20	0,10	0,05	0,01	0,001
6	5	6	6	—	—	26	16	17	18	20	22
7	6	6	7	7	—	27	17	18	19	20	22
8	6	7	7	8	—	28	17	18	19	21	23
9	7	7	8	9	—	29	18	19	20	22	24
10	7	8	9	10	10	30	18	20	20	22	24
11	8	9	9	10	11	32	19	21	22	24	26
12	8	9	10	11	12	36	22	23	24	26	28
13	9	10	10	12	13	40	24	25	26	28	31
14	10	10	11	12	13	44	26	27	28	31	33
15	10	11	12	13	14	48	28	29	31	33	36
16	11	12	12	14	15	52	30	32	33	35	38
17	11	12	13	14	16	56	32	34	35	38	40
18	12	13	13	15	16	60	34	36	37	40	43
19	12	13	14	15	17	64	36	38	40	42	45
20	13	14	15	16	18	68	38	40	42	45	48
21	13	14	15	17	18	72	41	42	44	47	50
22	13	14	15	17	19	76	43	45	46	49	52
23	15	16	16	18	20	80	45	47	48	51	55
24	15	16	17	19	20	84	47	49	51	54	57
25	16	17	18	19	21	88	49	51	53	56	59

NOTE 1 Values in the table are exact because they are based on the binomial distribution. For values of n not in the table, compute approximate values for the missing entries based on the normal approximation to the binomial as follows:

minimum number of responses (x) = nearest whole number greater than

$x = (n/2) + z\sqrt{n/4}$

where z varies with the significance level as follows: 0,84 for $\alpha = 0,20$; 1,28 for $\alpha = 0,10$; 1,64 for $\alpha = 0,05$; 2,33 for $\alpha = 0,01$; 3,09 for $\alpha = 0,001$.

NOTE 2 Values of $n < 24$ are usually not recommended for a duo-trio test for a difference.

- ✓ **When testing for similarity**

Use Table 5 to analyse the data obtained from a duo-trio test. If the number of correct responses is less than or equal to the number given in Table 5 (corresponding to the number of assessors, the β-risk level and the value of pd chosen for the test), conclude that no meaningful difference exists between the samples.

Table 5 — Maximum number of correct responses needed to conclude that two samples are similar, based on a Duo-Trio test (11)

n	β	p_d					n	β	p_d				
		10 %	20 %	30 %	40 %	50 %			10 %	20 %	30 %	40 %	50 %
20	0,001	3	4	5	6	8	52	0,001	17	19	22	25	28
	0,01	5	6	7	8	9		0,01	19	22	25	27	30
	0,05	6	7	8	10	11		0,05	22	24	27	30	33
	0,10	7	8	9	10	11		0,10	23	26	28	31	34
	0,20	8	9	10	11	12		0,20	25	27	30	33	35
24	0,001	5	6	7	9	10	56	0,001	18	21	24	27	30
	0,01	7	8	9	10	12		0,01	21	24	27	30	33
	0,05	8	9	11	12	13		0,05	24	27	29	32	36
	0,10	9	10	12	13	14		0,10	25	28	31	34	37
	0,20	10	11	13	14	15		0,20	27	30	32	35	38
28	0,001	6	8	9	11	12	60	0,001	20	23	26	30	33
	0,01	8	10	11	13	14		0,01	23	26	29	33	36
	0,05	10	12	13	15	16		0,05	26	29	32	35	38
	0,10	11	12	14	15	17		0,10	27	30	33	36	40
	0,20	12	14	15	17	18		0,20	29	32	35	38	41
32	0,001	8	10	11	13	15	64	0,001	22	25	29	32	36
	0,01	10	12	13	15	17		0,01	25	28	32	35	39
	0,05	12	14	15	17	19		0,05	28	31	34	38	41
	0,10	13	15	16	18	20		0,10	29	32	36	39	43
	0,20	14	16	18	19	21		0,20	31	34	37	41	44
36	0,001	10	11	13	15	17	68	0,001	24	27	31	34	38
	0,01	12	14	16	18	20		0,01	27	30	34	38	41
	0,05	14	16	18	20	22		0,05	30	33	37	40	44
	0,10	15	17	19	21	23		0,10	31	35	38	42	45
	0,20	16	18	20	22	24		0,20	33	36	40	43	47
40	0,001	11	13	15	18	20	72	0,001	26	29	33	37	41
	0,01	14	16	18	20	22		0,01	29	32	36	40	44
	0,05	16	18	20	22	24		0,05	32	35	39	43	47
	0,10	17	19	21	23	25		0,10	33	37	41	44	48
	0,20	18	20	22	25	27		0,20	35	39	42	46	50
44	0,001	13	15	18	20	23	76	0,001	27	31	35	39	44
	0,01	16	18	20	23	25		0,01	31	35	39	43	47
	0,05	18	20	22	25	27		0,05	34	38	41	45	50
	0,10	19	21	24	26	28		0,10	35	39	43	47	51
	0,20	20	23	25	27	30		0,20	37	41	45	49	53
48	0,001	15	17	20	22	25	80	0,001	29	33	38	42	46
	0,01	17	20	22	25	28		0,01	33	37	41	45	50
	0,05	20	22	25	27	30		0,05	36	40	44	48	53
	0,10	21	23	26	28	31		0,10	37	41	46	50	54
	0,20	23	25	27	30	33		0,20	39	43	47	52	56

Table 5 Continued

n	β	p_d					n	β	p_d				
		10 %	20 %	30 %	40 %	50 %			10 %	20 %	30 %	40 %	50 %
84	0,001	31	35	40	44	49	100	0,001	39	44	49	54	60
	0,01	35	39	43	48	52		0,01	42	47	53	58	64
	0,05	38	42	46	51	55		0,05	46	51	56	61	67
	0,10	39	44	48	52	57		0,10	48	53	58	63	68
	0,20	41	46	50	54	59		0,20	50	55	60	65	70
88	0,001	33	37	42	47	52	104	0,001	40	46	51	57	63
	0,01	37	41	46	50	55		0,01	44	50	55	61	66
	0,05	40	44	49	53	58		0,05	48	53	59	64	70
	0,10	41	46	50	55	60		0,10	50	55	60	66	71
	0,20	43	48	52	57	62		0,20	52	57	63	68	73
92	0,001	35	40	44	49	55	108	0,001	42	48	54	59	65
	0,01	38	43	48	53	58		0,01	46	52	57	63	69
	0,05	42	46	51	56	61		0,05	50	55	61	67	72
	0,10	43	48	53	58	63		0,10	52	57	63	68	74
	0,20	46	50	55	60	65		0,20	54	60	65	71	76
96	0,001	37	42	47	52	57	112	0,001	44	50	56	62	68
	0,01	40	45	50	56	61		0,01	48	54	60	66	72
	0,05	44	49	54	59	64		0,05	52	58	63	69	75
	0,10	46	50	55	60	66		0,10	54	60	65	71	77
	0,20	48	53	57	62	67		0,20	56	62	68	73	79

NOTE 1 * Values in the table are exact because they are based on the binomial distribution. For values of n not in the table, compute an approximate $100(1-\beta)$ % upper confidence limit for p_d based on the normal approximation to the binomial as:

$$[2(x/n)-1]+2z_\beta\sqrt{(nx-x^2)/n^3}$$

where

x is the number of correct answers;

n is the number of assessors;

z_β varies as follows: 0,84 for $\beta = 0,20$; 1,28 for $\beta = 0,10$; 1,64 for $\beta = 0,05$; 2,33 for $\beta = 0,01$; 3,09 for $\beta = 0,001$.

If the computed value is less than the selected limit for p_d, then declare the samples similar at the β level of significance.

NOTE 2 Values of $n < 36$ are usually not recommended for duo-trio test for similarity.

III.3 A-Not-A tests

There are two types of A-not-A tests referenced in the literature. The first and the more commonly used version has a training phase with the two products followed by monadic evaluation phase which is the standard A-not-A test. The second version is essentially a sequential paired difference test or simple difference test, which is called the alternate A-not A test. The alternate A-not-A test is not frequently used.

III.3.1 Alternate A-Not-A test

This is a sequential same/difference paired difference test where the panelist receives and evaluates the first sample, that sample is then removed. Subsequently, the panelist receives and evaluates the second sample. The panelist is then asked to indicate whether the two samples were perceived to be the same or different. Since the panelists do not have the samples available simultaneously they must mentally compare the two samples and decide whether they are similar or different. Thus, the panelists must be trained to understand the task as described by the score sheet but they need not be trained to evaluate specified sensory dimensions. The alternate A-not-A test, like the difference paired comparison method, has four serving sequences (AA, BB, AB, BA). These sequences should be randomized across panelists with each sequence appearing an equal number of times. The test is one tailed since the experimenter knows the correct answer to the question asked of the panelists namely whether the two samples are the same or different. The null hypothesis of the alternate A-not-A test is the same as the difference paired comparison null hypothesis (H_0: Ppc = 0.5). The alternative hypothesis for this form of the A-not-A test is that if the samples are perceptibly different the population will correctly indicate that the samples are the same or different more frequently than one in two times. This alternative hypothesis is also the same as that of the difference paired comparison test (HA: Ppc > 1/2).

The results of the A-not-A test only indicate whether the panelists could significantly discriminate between the samples when they are not presented simultaneously, no direction of difference is indicated. In other words, the sensory scientist will only know that the samples are perceptibly different but not in which attribute(s) the samples differed. This version of the A-not-A test is frequently used when the experimenter cannot make the two formulations have exactly the same color or shape or size, yet the color or shape or size of the samples are not relevant to the objective of the study. However, the differences in color or shape or size have to be very subtle and only obvious when the samples are presented simultaneously. If the differences are not subtle the panelists are likely to remember these and they will make their

decision based on these extraneous differences.

III.3.2 Standard A-Not-A Test

Panelists inspect multiple examples of products that are labeled "A" and usually also products that are labeled "not-A." Thus there is a learning period. Then once the training period has been completed the panelists receive samples one at a time and are asked whether each one is either A or not-A. The standard A-not-A test potentially has four different designs. For the monadic A-not-A test the panelist, after the training phase, is presented with a single sample (either A or not-A). In the paired A-not-A version the panelist, after completion of the training phase, is presented with a pair of samples, sequentially (one A and one not-A, counter balanced across panelists). In the replicated monadic A-not-A version the panelist, after completion of training, receives a series of samples of either A or not-A but not both. This version is rarely used in practice. Lastly, in the replicated mixed A-not-A version the panelist, after completion of training, receives a series of A and not-A samples. Each of these different formats requires different statistical models and using an inappropriate model could lead to a misleading conclusion.

III.4 "2 out of 5" test

The "2 out of 5" test is a method of discrimination testing designed to determine the existence a difference between two products (A and B) where the number of samples in a line-up is increased to five. One of the products is represented by two coded sample; the other product – by the rest of the coded samples in the line-up. The products can be mixed in a variety of line-ups: AAABB, ABABA, BBBAA, BABAB, AABAB, BAABA, BBABA, ABBAB, ABAAB, ABBAA, BABBA, BAABB, BAAAB, BABAA, ABBBA, ABABB,

AABBA, BBAAA, BBAAB, AABBB. The panelists are then asked to inspect the samples, group them based on the similarity, and provide a feedback on the nature of a difference between two formed groups. On average, 10-20 assessors can be used for "2 out of 5" test. If the panelists are highly trained and/or the difference between the samples is relatively easy to identify, 5-6 assessors are sufficient.

III.5. Ranking and rating tests

Intensity ranking tests involve tasters ranking samples according to the perceived intensity of a sensory characteristic. This type of test can be used to obtain preliminary information about differences between products or to identify tasters who are able to distinguish differences between samples with known differences. These tests can indicate whether there are perceptible differences in intensity for an attribute in several samples, but ranking does not provide information on the magnitude of the difference between two samples. There may be only a small difference between samples ranked 1 and 2, but it may be perceptible in intensity,

while the difference between samples ranked 2 and 3 may be much greater. Simple ranking does not provide this type of information.

III.5.1 Description of the tasters' task

Expert tasters are asked to rank coded samples according to the intensity of a given characteristic, ranking the samples in descending order for the intensity of that characteristic. As a general rule, ties are not allowed.

III.5.2 Presentation of samples

Tasters are presented with three or more samples in identical containers, coded with a random 3-digit number. Each sample has a different code number. All samples are presented simultaneously to each taster in a predetermined or randomly selected order. Tasters are allowed to taste the samples as often as necessary to make the necessary comparisons between them.

III.5.3 Data analysis

Once all the tasters have ranked the samples, the rankings assigned to each sample are totaled. The significance of any differences is then verified by comparing the ranking totals between all possible pairs of samples using the Friedman test and Statistical Tables 6 and 7.

Table 6. Differences in absolute rank sums critical for comparisons of “all treatments” at a 5% significance level (12)

Testers	Number of samples									
	3	4	5	6	7	8	9	10	11	12
3	6	8	11	13	15	18	20	23	25	28
4	7	10	13	15	18	21	24	27	30	33
5	8	11	14	17	21	24	27	30	34	37
6	9	12	15	19	22	26	30	34	37	42
7	10	13	17	20	24	28	32	36	40	44
8	10	14	18	22	26	30	34	39	43	47
9	10	15	19	23	27	32	36	41	46	50
10	11	15	20	24	29	34	38	43	48	53
11	11	16	21	26	30	35	40	45	51	56
12	12	17	22	27	32	37	42	48	53	58
13	12	18	23	28	33	39	44	50	55	61
14	13	18	24	29	34	40	46	52	57	63
15	13	19	24	30	36	42	47	53	59	66
16	14	19	25	31	37	42	49	55	61	67
17	14	20	26	32	38	44	50	56	63	69
18	15	20	26	32	39	45	51	58	65	71
19	15	21	27	33	40	46	53	60	66	73
20	15	21	28	34	41	47	54	61	68	75
21	16	22	28	35	42	49	56	63	70	77
22	16	22	29	36	43	50	57	64	71	79
23	16	23	30	37	44	51	58	65	73	80
24	17	23	30	37	45	52	59	67	74	82
25	17	24	31	38	46	53	61	68	76	84
26	17	24	32	39	46	54	62	70	77	85
27	18	25	32	40	47	55	63	71	79	87
28	18	25	33	40	48	56	64	72	80	89
29	18	26	33	41	49	57	65	73	82	90
30	19	26	34	42	50	58	66	75	83	92
31	19	27	34	42	51	59	67	76	85	93
32	19	27	35	43	51	60	68	77	86	95
33	20	27	36	44	52	61	70	78	87	96
34	20	28	36	44	53	62	71	79	89	98
35	20	28	37	45	54	63	72	81	90	99
36	20	29	37	46	55	63	73	82	91	100
37	21	29	38	46	55	64	74	83	92	102
38	21	29	38	47	56	65	75	84	94	103
39	21	30	39	48	57	66	76	85	95	105
40	21	30	39	48	57	67	76	86	96	106
41	22	31	40	49	58	68	77	87	97	107
42	22	31	40	49	59	69	78	88	98	109
43	22	31	41	50	60	69	79	89	99	110
44	22	32	41	51	60	70	80	90	101	111
45	23	32	41	51	61	71	81	91	102	112
46	23	32	42	52	62	72	82	92	103	114
47	23	33	42	52	62	72	83	93	104	115
48	23	33	43	53	63	73	84	94	105	116
49	24	33	43	53	64	74	85	95	106	117
50	24	34	44	54	64	75	85	96	107	118
55	25	35	46	56	67	78	90	101	112	124
60	26	37	48	59	70	82	94	105	117	130
65	27	38	50	61	73	85	97	110	122	135
70	28	40	52	64	76	88	101	114	127	140
75	29	41	53	66	79	91	105	118	131	145
80	30	42	55	68	81	94	108	122	136	150
85	31	44	57	70	84	97	111	125	140	154
90	32	45	58	72	86	100	114	129	144	159
95	33	46	60	74	88	103	118	133	148	163
100	34	47	61	76	91	105	121	136	151	167

Table 7. Differences in absolute rank sums critical for comparisons of "all treatments" at a 1% significance level (12)

Testers	Number of samples									
	3	4	5	6	7	8	9	10	11	12
3	—	9	12	14	17	19	22	24	27	30
4	8	11	14	17	20	23	26	29	32	36
5	9	13	16	19	23	26	30	33	37	41
6	10	14	18	21	25	29	33	37	41	45
7	11	15	19	23	28	32	36	40	45	49
8	12	16	21	25	30	34	39	43	48	53
9	13	17	22	27	32	36	41	46	51	56
10	13	18	23	28	33	38	44	49	54	59
11	14	19	24	30	35	40	46	51	57	63
12	15	20	26	31	37	42	48	54	60	66
13	15	21	27	32	38	44	50	56	62	68
14	16	22	28	34	40	46	52	58	65	71
15	16	22	28	35	41	48	54	60	67	74
16	17	23	30	36	43	49	56	63	70	77
17	17	24	31	37	44	51	58	65	72	79
18	18	25	31	38	45	52	60	67	74	81
19	18	25	32	39	46	54	61	69	76	84
20	19	26	33	40	48	55	63	70	78	86
21	19	27	34	41	49	56	64	72	80	88
22	20	27	35	42	50	58	66	74	82	90
23	20	28	35	43	51	59	67	75	84	92
24	21	28	36	44	52	60	69	77	85	94
25	21	29	37	45	53	62	70	79	87	96
26	22	29	38	46	54	63	71	80	89	98
27	22	30	38	47	55	64	73	82	91	100
28	22	31	39	48	56	65	74	83	92	101
29	23	31	40	48	57	66	75	85	94	103
30	23	32	40	49	58	67	77	86	95	105
31	23	32	41	50	59	69	78	87	97	107
32	24	33	42	51	60	70	79	89	99	108
33	24	33	42	52	61	71	80	90	100	110
34	25	34	43	52	62	72	82	92	102	112
35	25	34	44	53	63	73	83	93	103	113
36	25	35	44	54	64	74	84	94	105	115
37	26	35	45	55	65	75	85	95	106	117
38	26	36	45	55	66	76	86	97	107	118
39	26	36	46	56	66	77	87	98	109	120
40	27	36	47	57	67	78	88	99	110	121
41	27	37	47	57	68	79	90	100	112	123
42	27	37	48	58	69	80	91	102	113	124
43	28	38	48	59	70	81	92	103	114	126
44	28	38	49	60	70	82	93	104	115	127
45	28	39	49	60	71	82	94	105	117	128
46	28	39	50	61	72	83	95	106	118	130
47	29	39	50	62	73	84	96	108	119	131
48	29	40	51	62	74	85	97	109	121	133
49	29	40	51	63	74	86	98	110	122	134
50	30	41	52	63	75	87	99	111	123	135
55	31	43	54	66	79	91	104	116	129	142
60	32	45	57	69	82	95	108	121	135	148
65	34	46	59	72	86	99	113	126	140	154
70	35	48	61	75	89	103	117	131	146	160
75	36	50	64	78	92	106	121	136	151	166
80	37	51	66	80	95	110	125	140	156	171
85	38	53	68	83	98	113	129	144	160	176
90	40	54	70	85	101	116	132	149	165	181
95	41	56	71	87	103	120	136	153	169	186
100	42	57	73	89	106	123	140	157	174	191

IV. INSTRUMENTAL METHODS OF SENSORY ANALYSIS

One of the main limitations when implementing sensory tests is the number of required panelists, ranging from 7 to 100 depending on the test type. This implies an investment of human and economic resources, raw materials, and/or time. This limitation has motivated researchers to generate technologies to identify and quantify some sensory characteristics of foods with greater precision.

Such developments search to mimic the functioning of the five senses, such is the case of electronic noses (e-noses) and tongues (e-tongues), which upon contact with food, generate an electronic response from a chemical interaction, which is interpreted by a digital information processing system. Similarly, image analysis through devices such as cameras seek to simulate the sense of eyesight ; concerning touch and hearing, some reports show various technological tools that measure force and sound, seeking to imitate the behavior of these senses.

IV.1 Electronic nose (e-nose)

Odor is one of the most representative attributes of food. This can be expressed as one of the qualities of Volatile Organic Compounds (VOCs), so unique and distinctive that they are considered fingerprints. Generally, the sensory analysis method to identify such components is performed by panelists who rate and classify on different scales the odor perceived in the sample. On the other hand, different methods have been developed for the identification of VOCs, which are characterized by high accuracy and reliability, such as: Gas Chromatography-Olfactometry (GC-O), Gas Chromatography-Mass Spectrometry (GC-MS), Headspace Solid Phase Microextraction (HS-SPME), as some of the most used methods. Devices such as the e-nose have been developed, consisting of an array of electrochemical sensors articulated with a pattern recognition system that identifies, groups, and discriminates the VOCs. This has become an alternative to generating fast and reliable results in the food industry.

IV.1.1 The internal structure of the e-nose

For the articulation of three fundamental systems characterizes E-nose: sensing, electrical conditioning, and pattern recognition (Figure 10). The sensing system is composed of a matrix of sensors that can be of different types such as: conductivity, polymers, intrinsic conductive polymers, metal oxide, surface acoustic waves, and quartz crystal balance, which allow the detection of VOCs through absorption, adsorption, or chemical reaction methods. Depending on the characteristics of the food matrix to be evaluated, the sensors that make up the e-nose

must be carefully considered, as they will react more efficiently to certain particles. This detection produces an electronic signal, from which it is possible to characterize the VOCs.

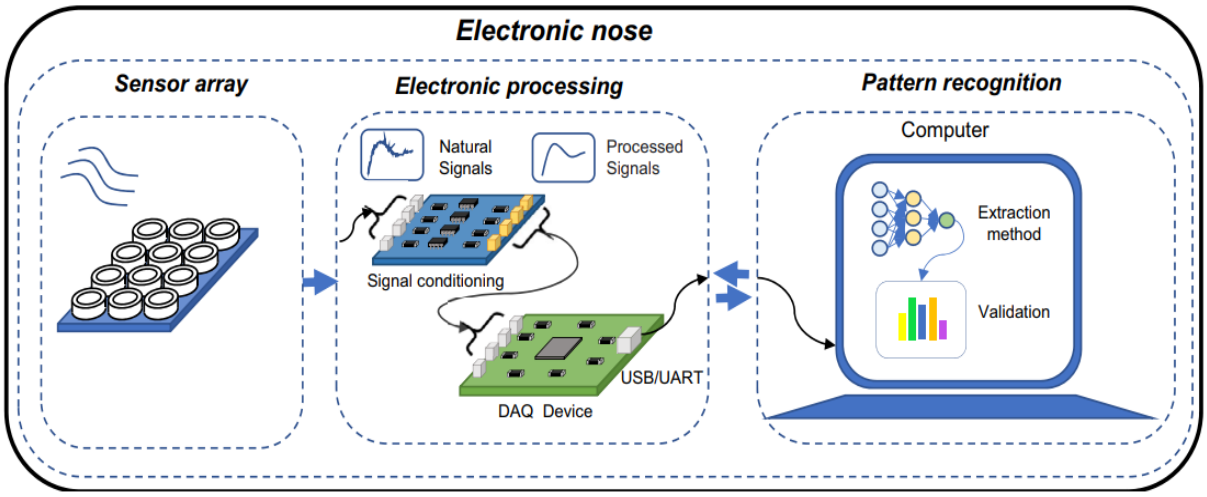

Figure 10. Fundamental stages of operation of an electronic nose (13).

The electrical conditioning system is responsible for matching the signal emitted by each of the sensors. Signal matching consists of amplification and filtering to identify the analyzed food matrix sample. Finally, the pattern recognition system receives the already conditioned electrical signal and is in charge of processing it. For this procedure, extraction methods are used, which aim to obtain reliable and robust information from the electrical signal, guaranteeing greater measurement efficiency.

IV.1.2 E-nose applications

E-nose is used in several food matrices to identify their authenticity due to the growing number of counterfeit products that represent a significant risk to the health of consumers. Additionally, this device also allows users to identify and group according to their specifications some food matrices such as: alcoholic beverages, dairy products, and juices ; the ripeness of fruits and vegetables; quality of meats; shelf life of grains, among others.

IV.2 Electronic tongue (e-tongue)

The human tongue can identify five basic tastes: sour, salty, sweet, bitter, and umami. Usually, the evaluation and classification of the basic flavors of a product are done through trained panelists and sometimes consumers. However, these measurements can be subjective, which can be reduced by using technological tools such as the e-tongue, thus ensuring repeatability and reproducibility of the results. Different investigations have shown that by using the e-tongue, it is possible to determine the quality, adulteration, classification, or origin of food.

IV.2.1 The internal structure of the e-tongue

E-tongue is characterized for articulating three fundamental systems: sensing, electrical conditioning, and pattern recognition (Figure 11). E-tongue sensing system is composed of two or more electrodes, each electrode has a membrane that upon contact with the analyte generates a chemical interaction causing a reversible change in the electronic properties, which allows the characterization of the food matrix. Potentiometric-type electrodes measure the voltage differences between the working and the reference electrodes. The voltage change in the measurement given by the working electrode will have a proportional relationship to the concentration of the analyte.

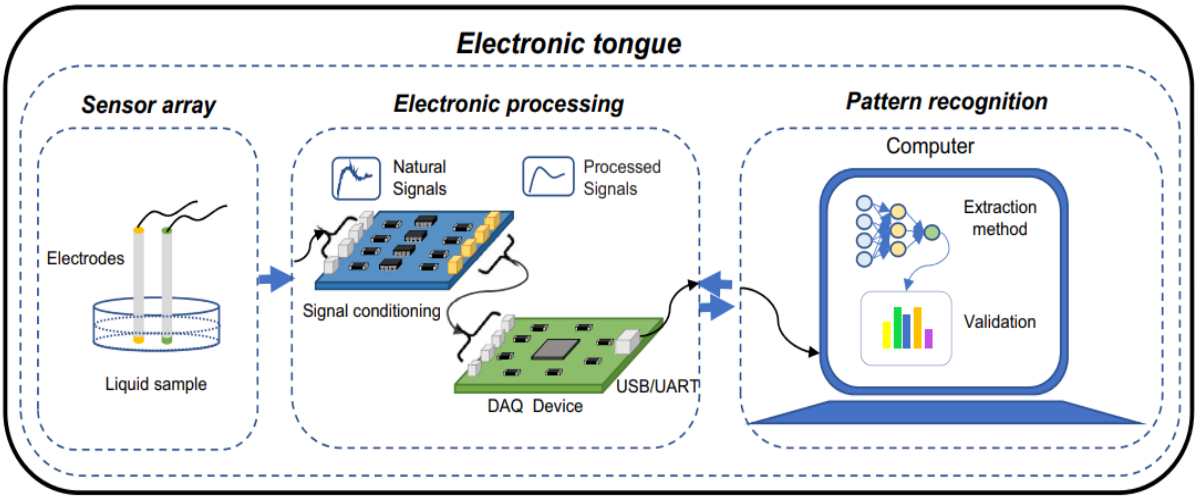

Figure 11. Fundamental stages of operation of an electronic tongue (13).

IV.2.2 E-tongue applications

The use of the e-tongue in the food industry encompasses a wide range of applications, including discrimination by type and place of origin, verification of authenticity, adulteration or counterfeiting, and quantification of food matrix components. A clear example of the use of such technology for classifying products by type and place of origin is evidenced where a potentiometric e-tongue was used to classify 60 samples of olive oil.

IV.3 Artificial Vision System

Computer Vision System (CVS) also known as Artificial Vision System (AVS), is an image analysis tool used to obtain information about objects through them. This is due to its ability to characterize: shape, size, color, and other particularities of the object, which can be static or moving. Therefore, the CVS can be used in both continuous and static production lines, achieving a real-time analysis, as it allows fast, accurate, and non-invasive captures, with

reliable and reproducible results. Due to its flexibility and technological development, a CVS can store information about an object to perform further analysis using new images. Thus, the CVS becomes an alternative to avoid the possible errors of quality inspection of the objects which the human eye can incur.

IV.3.1 CVS internal structure

A CVS is composed of three fundamental stages: illumination, image detection, and pattern recognition (Figure 12). The first stage plays an important role in image acquisition, since light has a direct impact on the clarity and color of the images and its improper use can generate shadows and unwanted reflections, cataloged as noise in the images. Therefore, depending on the application of the system, an appropriate selection of the light-generating elements must be made, considering characteristics such as wavelength, intensity, and direction. These light-generating elements can be light bulbs (incandescent, fluorescent, halogen), lasers, light emitting diodes (LEDs), X-ray tubes, and infrared lamps. Two of the most commonly used technologies in the second stage are cameras or scanners, which are responsible for taking an image of the object to be analyzed. Cameras capture a two-dimensional image instantaneously, while scanners take a line of pixels in an instant of time, so it requires a mechanism that performs a displacement of the scanner or the object to capture a succession of data and thus obtain the two-dimensional image. Internally, these devices have specialized sensors that can capture color, monochromatic, thermal, or ultraviolet images depending on their characteristics.

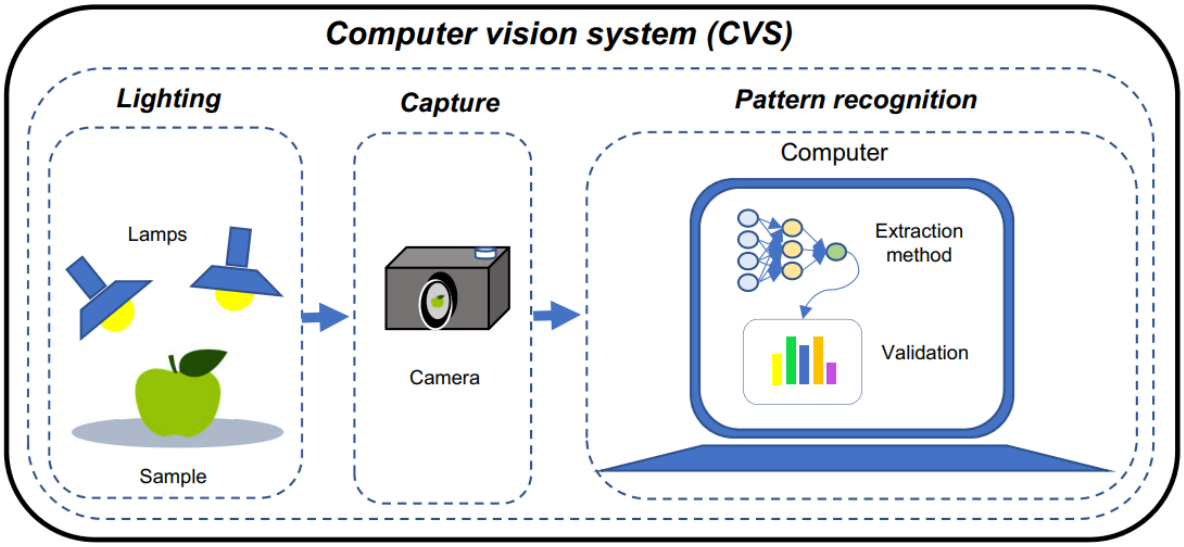

Figure 12. Fundamental stages of operation of a machine vision system (13).

Finally, the third stage aims to extract quantitative and qualitative information from the image using an analysis algorithm usually run on a processor. Given the versatility and advantages presented by a CVS, the food industry has been implementing these systems to identify properties such as: morphology, color, texture, freshness, and quality.

IV.3.2 CVS applications

The applications that recurrently use CVS are focused on the classification and prediction of the characteristics of a food matrix, whether it is an individual analysis, a production batch, or harvesting. Evaluate and determine the freshness of beef based on color and texture obtained by a portable custom designed CVS.

Other applications of CVS systems are in fruits and vegetables, through the identification of color, length, diameter, and weight

IV.4. Texture analyzer

The texture of a food is perceived through the response to the contact between the body part and the food. It is a determining characteristic in the acceptance of the product by the consumer. Texture is a quality attribute used in the food industry, allowing the parameterization and standardization of food products. For example, freshness, a determining characteristic in selecting a vegetable or fruit, can be described by its hardness. The latter is one of the primary properties of texture, as well as cohesiveness, viscosity, elasticity, and adhesiveness.

IV.4.1 Texture Analyzer Internal Structure

The texture analyzer usually has three fundamental parts: a moving beam, a load cell, and a control panel. The first part has a mechanical system that performs the precise vertical displacement of the beam where the load cell is supported; these mechanisms work with a spindle-type system, which has a motor coupled to it that transmits the controlled circular motion. The load cells are electrical elements that generate a voltage signal when they come into contact with a surface. The cells used are in a range of operation from 100 g to 500 kg, which will depend on the design of each manufacturer's analyzer. With the basic structure of the texture analyzer already mentioned, a variety of probes can be incorporated, which, coupled with the load cell, make it possible to measure a large part of the common texture parameters in foodstuffs.

IV.4.2 Texture analyzer applications

Some applications in which the texture analyzer is used are evidenced in investigations such as cooking methods and the marination.

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