Objective measurement of pungency, bitterness, and astringency in food

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ABSTRACT

In the food sector, sensory evaluation is crucial for food and new food products. Objective measurement of sensory characteristics is a tool used to assess food preference using instruments.

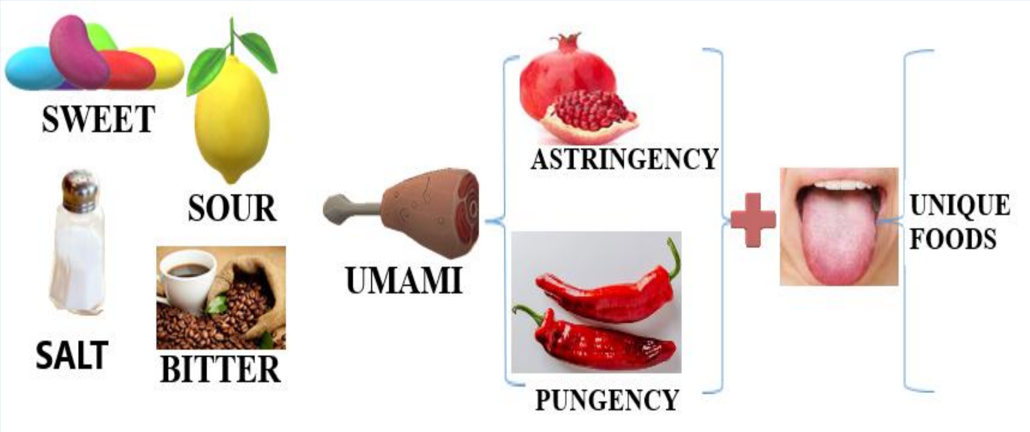
The sources of information were the following scientific databases: Scopus, ScienceDirect, PubMed, ResearchGate, the FFHDJ/FFC journal ecosystem and Google Scholar. The parameters of the publications were as follows: publications from 1978 until 2025 (61 references were selected for this review).

In the present study, the differences between subjective and objective tests were presented. The basic tastes perceived subjectively by the tongue such as sweetness, sourness, saltiness, and bitterness– were reviewed, along with metallic and umami tastes. Umami, the fifth taste, was described as contributing to the characteristic flavor of umami-Tastes, their reference substances, and concentrations were summarized. Mouthfeels such as pungency and astringency were reviewed in depth. Furthermore, the characterization of pungency and the associated Scoville Heat Units (SHU), including pungency levels of capsaicinoids, as well as the pungency of ginger and cinnamon, and the pungency of onion and garlic, were explained. The sources of bitterness, bitterness measurement using the International Bitterness Units scale (IBU), bitterness determination, debittering techniques, and food bitterness and pungency regulations were described. Astringency causes, factors affecting, astringency measurement using different objective techniques and quantifying astringency using the gelatin index, and de-astringency of food to increase edibility were also considered.

Novelty: This review highlights the importance of using objective measurement tools to determine tastes and mouthfeels of new foods or food products during development and processing. Integrating the health implications of taste/mouthfeel compounds with strategies to debitter and de-astringe nutritional and nutraceutical components to improve edibility provides a distinctive contribution.

This review can be helpful for consumers, food manufacturers, and catering and food service industries in understanding, choosing, and dealing with key sensory attributes (i.e., basic tastes, pungency, bitterness, and astringency) of foods, spices, and spicy food and other related substances for their sensory preferences.

Keywords: sensory evaluation, subjective tests, basic tastes, mouthfeel, Scoville, functional foods



Graphical Abstract: Common examples of foods/taste substances for both the basic tastes and mouthfeels.

INTRODUCTION

The organoleptic evaluation tests of foods are commonly used in food processing as well as other applications, such as the development of new products, product improvement, reduction of costs, product quality, product storability and stability, and product grading. Sensory evaluation is defined as the examination of sensory attributes of a product by the human sense organs (i.e., eyes, tongue, nose, ears, and fingers) to establish the acceptability degree among customers [1]. Food evaluation is classified into two groups of tests as follows: subjective evaluation (using sense organs) and objective evaluation. Table 1. shows the differences between subjective and objective tests.

Table 1. The differences between subjective and objective tests.

Subjective tests	Objective tests
- Measuring food characteristics using different senses (i.e., sight, smell, hearing, taste, and touch).	- Measuring food characteristics using equipment or official methods (i.e., chemical, physical and microscopic).
- Uses individuals.	- Objective tests are not dependent on observations of individuals.
- Results are variables.	- Results are repeatable.
- Can determine acceptability of consumer.	- Can't determine acceptability of consumer.
- Time-consuming.	

Subjective tests	Objective tests
- Expensive. - Important for the development of products.	- Faster. - Cheap. - Important for routine quality control.

Four basic tastes can be perceived subjectively by the tongue, including sweetness, sourness, saltiness, and bitterness, in addition to umami and metallic tastes (Table 2). Umami (savory/savoriness), the fifth taste, gives umami-rich foods (glutamate-containing food i.e., tomatoes, onions, peas, carrots, asparagus, celery, broccoli, mushroom, milk, cheese, beet, and ginger. Inosinate-containing food i.e., meat, fish, poultry, and pork. Guanylate-containing food i.e., dried shitake) their distinctive taste. Also, aspartate and adenylate salts serve as types of umami substances. Umami intensity in food is recorded as equal umami concentration, which means the amount of umami amino acids and 5′-nucleotides [2].

The best-estimate threshold of ferrous sulfate heptahydrate $7H_2O$ is used for testing metallic taste [3].

Table 2. Tastes, their reference materials, and concentrations [4].

Taste	Reference material	Concentration g/l
Sourness	Citric acid	1.20
Bitterness	Caffeine	0.54
Saltiness	NaCl	4.00
Sweetness	Sucrose	24.00
Glutamate	Monosodium glutamate	2.00
Metallic	Ferrous sulfate $7H_2O$	0.012

Objective procedures include the use of instruments to evaluate sensory criteria in foods instead of relying solely on human sensory organs [5].

The purpose of this study is to highlight the importance of using objective measurement tools in determining taste and mouthfeel attributes of new foods or food products in food plants and provide an accesible overview of the pungency, bitterness, and astringency of foods.

OBJECTS AND METHODS

The sources of information were the following scientific databases: Scopus, ScienceDirect, PubMed, ResearchGate, the FFHDJ/FFC journal ecosystem and Google Scholar. The search strategy included the following keywords: sensory evaluation, subjective tests, basic tastes, mouthfeel, functional foods and Scoville. The following inclusion criteria were considered: studies addressing the differences between subjective and objective tests; the four basic tastes (sweetness, sourness, saltiness, and bitterness), in addition to metallic and umami. Mouthfeels such as pungency and astringency, pungency characterization, and capsaicinoids and their pungency levels using Scoville heat units (SHU), ginger pungency, and onion and garlic pungency. Additional topics included bitterness causes, bitterness measurement, debittering procedures, and food bitterness and pungency regulations. Astringency causes and measurement.

The parameters of the publications were as follows: publications from 1978 to 2025 (61 references were selected for this review); language: English. Exclusion criteria: lack of access to the full-text articles. Based on the review, the author compiled information on the discussion of objective measurement of pungency, bitterness and astringency in food.

Pungency: Spiciness, hotness, heat or piquancy (pungency) of peppers, spicy foods, and other substances is considered the 6th taste. The pungency of peppers and spicy foods is recorded in Scoville heat units (SHU). SHU is a subjective measurement of pungency (hotness) and is based on the concentration of capsaicinoids (i.e., capsaicin and dihydrocapsaicin) in chili peppers (Figure 1), and the pungent component of black and white peppers *(Piper nigrum)* is piperine. According to Scoville Heat Units (SHU), there are five categories of pungency, as shown in Table 3. Nwokem *et al.,* [6] reported that yellow pepper (*Capsicum chinense*) is the most pungent (containing the highest concentration of capsaicin, being 9.177 ± 0.268 mg/g and having a pungency level of 146,823.20 SHU), whereas the lowest capsaicin concentration (1.189 ± 0.073 mg/g) and pungency level (19,015.20 SHU) were found in Zaria tatase (*Capsicum annuum*). Li *et al.,* [7] established the “Li Spicy Unit” (LSU) as a new pungency degree unit (based on sensory evaluation by customers and capsaicinoids content) used for spicy foods. Capsaicin content was determined using various procedures such as HPLC [7, 8,], ultra-fast liquid chromatography (UFLC) [9-10], HPLC with electrochemical detection (HPLC-EC) [11], and UV spectrometry [12].

Ginger *(Zingiber officinale)* is well known for its pungency due to gingerol and its derivatives (i.e., gingerols, shogaols, paradols, zingerone, gingerdiones, and gingerdiols) [13-14]. Ginger oil, or oleoresin, is extracted from dried ginger and used in beverages and confectioneries. Furthermore, milled dried ginger is used as an ingredient in spice formulas and in food manufacturing [15]. Dehydration temperature and puffing causes the conversion of gingerol to shogaol. Shogaol has a higher pungency than gingerol [13-16]. The pungency of fresh ginger (gingerol) is 60,000 SHU, while in dried or cooked ginger (shogaol) is 160,000 SHU [17]. Ginger has a milder pungency (Gingerol, 60,000 SHU) than capsicum.

The pungency of onions (*Allium cepa* L.) and garlic (*Allium sativum*) is measured according to the Pyruvate Scale (pyruvic acid content). Onion pungency is recorded as pyruvic acid content (micromoles of pyruvic acid per gram of fresh onion weight, μmoles/g FW). Kato *et al.,* [18] irradiated seeds using a neon-ion beam at 20 Gy for producing tearless and non-pungent onions. Garlic pungency is caused by sulfur compounds such as allicin and diallyl disulfide [19].

The principal pungent substance in mustard, horseradish, wasabi, and rocket (some *Brassicaceae* vegetables that have glucosinolate, and isothiocyanate originates from the glucosinolate) is Allyl Isothiocyanate [20-21]. According to pungency level, there are three types of mustard as follows: sweet, mild, and hot. Also, the pungency of cinnamon (*Cinnamomum verum*) is mainly related to its cinnamaldehyde content [22]. Table (4) presents a summary of the primary pungent substances in some pungent fruits, vegetables, and spices.

Table 3. Pungency characterization and the related Scoville Heat (SHU) Units [23].

Pungency characterization	**SHU**
Non-pungent	0-700
Mildly pungent	700-3,000
Moderately pungent	3,000-25,000
Highly pungent	25,000-70,000
Very highly pungent	>80,000

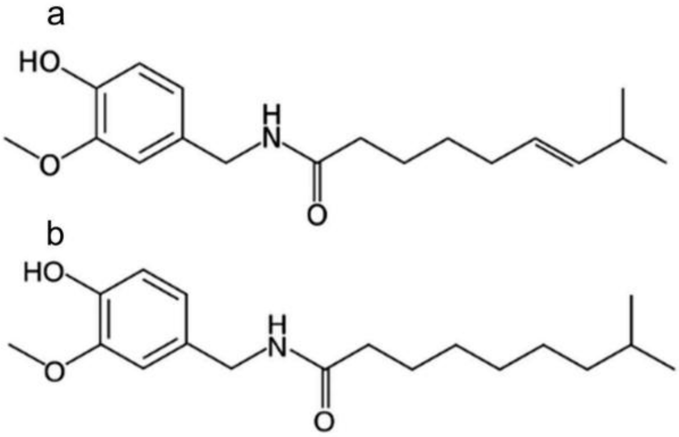


Figure 1. The chemical structure of capsaicin (a) and dihydrocapsaicin (b) [7].

Different capsaicinoids and their pungency using Scoville heat units (SHU) were reported by Panda and Suresh [12] as follows:

- Capsaicin (16,000,000 SHU),
- Dihydrocapsaicin (15,000,000 SHU),
- Nordihydrocapsaicin (9,100,000 SHU),
- Homodihydrocapsaicin (8,600,000 SHU),
- Homocapsaicin (8,600,000 SHU), and
- Nonivamide (9,200,000 SHU).

Table 4. The primary pungent substances of some pungent ingredients.

Pungent ingredients	**Principal pungent substances**
Chili peppers	Capsaicinoids
Black and white peppers	Piperines
Ginger	Gingerol and its derivatives
Onions and garlic	Sulfur compounds, diallyl disulfides, allicin
Mustard, horseradish, wasabi, and rocket	Allyl isothiocyanates
Cinnamon	Cinnamaldehydes

Health Implications: Capsaicinoids are phytochemical components and categorized as GRAS (Generally Regarded as Safe) compounds. The daily dietary consumption of capsaicinoids might range from 0.5 to 4 mg/kg [24]. Because capsaicinoids provide health advantages beyond basic pungent mouthfeel, its position in functional foods is especially notable. Food pungency components have desirable biological activities such as an antioxidant [25], antimicrobial [26], anti-cancer [27], anti-hypoglycemic, anti-hypolipidemic, analgesic, anti-inflammatory, and intestinal health-protecting activities [28].

Functional foods and capsaicinoids relationships: Fruits and vegetables are excellent providers of bioactive compounds. Important bioactive components, such as carotenoids, ascorbic acid (vitamin C), phenolic compounds, capsaicinoids, and capsinoids, are abundant in peppers which support human health [29]. In most Capsicum species, pungency (Capsaicinoids) is a primary attribute, and Capsaicinoids are synthesized in the pericarp, seeds, placental tissues, and other vegetative organs such as the capsicum plant's stems and leaves [27].

Bitterness: Food bitterness (tea, coffee, cocoa, beer, etc.) is a unique taste. The major contributors to bitterness are iso-acids. There are three types of iso-acids, such as humulone, cohumulone, and adhumulone [30], limonin, alkaloids, polyphenols, terpenoids, and free bitter amino acids [31]. Bitterness is recorded in the International Bitterness Units scale (IBU). Bitterness in non-alcoholic beer is ranged between 12 and 77 IBU [32]. Several researchers reported new procedures and techniques for measuring bitterness, such as fluorescence-based UV-LED system [30], spectrophotometry at 225 nm in extra virgin olive oil [33], fast fluorescence spectroscopic methods in beer [34], the electronic tongue [33], spectrophotometry and HPLC [36-38]. Factors influencing bitterness in alcoholic beverages are raw materials used, microbial metabolism during the fermentation process, processing and aging, and sensory interactions of several flavor substances [39].

Debittering methods: Several authors proposed many debittering methods such as immobilized naringinase for debittering (converting naringin into tasteless naringenin), in citrus (grapefruits, oranges, lemons, etc.) juices [40-41-42], physical adsorption in a resin [43], repeated blanching at 65°C [36], a Styrene-divinylbenzene Adsorbent Resin [44], and electrospun nylon-6 nanofibrous membranes [45], “Amberlite XAD-7HP” adsorbent [46].

Health Implications: Food bitterness constituents have a wide range of desirable activities, i.e., anti-hyperlipidemic, anti-hypertensive, anti-hyperglycemic, anti-inflammatory, antitumor, antibacterial, and antioxidant effects [31]. Therefore, they are also valuable components of medications and nutraceuticals.

Food bitterness and pungency regulations: According to Article 1293 of the Argentine Food Code [47], harmful bitter substances are prohibited for use in food processing, such as alkaloids (present in barley, coca, and some beans). In contrast, permitted bitter substances include chicory, sweet calamus, and blessed Thistle [47]. At high concentrations, capsaicinoids may be harmful (toxic) to humans; therefore, their concentrations should be regulated and clearly established in spicy products [48].

Astringency: An astringent is the mouthfeel (not a taste) caused by tannins (polyphenols) in unripe fruits such as unripe bananas, pomegranates, lemons, cashews, some berries, as well as some teas, coffee, and red grape wines. The Mean Degree of Polymerization (mDP) of tannins is often used to characterize the astringency in foods. As a simple mechanism of astringency, Llaudy *et al.,* [49] stated that astringency results from certain phenolic substances' capacity to bind salivary proteins (i.e., proline and hydroxyproline), which causes the mouth to feel dry and rough.

The main cause of astringency in aronia berry juice is proanthocyanidins [50], high levels of tannins in unripe green apples [51], polyphenols, organic (i.e., acetic acid, butanoic acid, quinic acid, adipic acid, lactic acid, malic acid, tartaric acid, citric acid) and inorganic (i.e., HCl, H_3PO_4) acids, some dehydrating agents (i.e., ethanol, acetone, glycerin, etc.), some metal ions such as Al, Mg, Fe, Zn, Ca, etc. [52]. The objective method of quantifying astringency is the gelatin index (absorbance of tannins is measured at wavelength 550 nm after acid hydrolysis, then the precipitation of all tannins using an excess of gelatin, and tannins are measured again). The gelatin index is a ratio between the two measurements of tannins [49-53]. Llaudy *et al.,*[49] used ovalbumin instead of gelatin to measure astringency (as a new method). Ujihara *et al.,* [54] measured astringent taste intensity in Matcha (green tea) using the taste sensor system; likewise, Hirono [55] observed an inhibitory effect of pectin on the astringent taste of catechins using a taste sensor system. Han *et al.,* [56] established a new method for measuring the astringency of herbs using an electronic tongue. Also, Zou *et al.,* [57] evaluated the astringency of green tea using an electronic nose.

Astringent persimmon *(Diospyros kaki)* contains a strong astringent (i.e. tannin component called diospyrin) taste [58]. González *et al.,* [59] performed de-astringency treatment of persimmon fruits using drying (hanging the whole fruit in a well-ventilated place) for 20 days.

There are several factors affecting astringency, such as saliva composition, oral pH, oral temperature, oral cavity properties, and oral fluid viscosity [60].

Food de-astringency for improving edibility, using various procedures such as hot water, mechanical damage, irradiation, ultra-sonication, ethanol, ethylene, lime water, CO_2, N_2, enzymes and gene-editing approaches, as stated by Zhao [61].

CONCLUSION

Using objective tools in sensory evaluation of food is highly significant in food and new food product development. This review can be helpful for consumers, food manufacturers, and catering and food service industries in understanding, choosing, and dealing with the key sensory characteristics (i.e., basic tastes, pungency, bitterness, and astringency) of foods, spices, spicy foods, and other related substances for their sensory preferences. Consequently, this may increase competition among local and global companies. Finally, objective measurement of food evaluation should be conducted in parallel with subjective sensory evaluation.

List of Abbreviations: SHU: Scoville Heat Units; IBU: International Bitterness Units; LSU: Li Spicy Unit; UFLC: ultra-fast liquid chromatography; HPLC-EC: HPLC with electrochemical detection; mDP: The Mean Degree of Polymerization of tannins.

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