Received: 27 November 2018 | Revised: 2 January 2019 | Accepted: 6 January 2019
DOI: 10.1111/jtxs.12392

INVITED REVIEW

WILEY Journal of Texture Studies

The instrumental texture profile analysis revisited

Micha Peleg

Department of Food Science, University of Massachusetts, Amherst, Massachusetts

Correspondence
Micha Peleg, Department of Food Science, University of Massachusetts, Amherst, MA 01003.
Email: micha.peleg@foodsci.umass.edu

Abstract

Although innovative at the time of their inception, all the historic and extant instrumental texture profile analysis (TPA) versions have serious methodological flaws. Their measured and calculated parameters, for example, "hardness," "brittleness," and "cohesiveness," bear only a remote relationship to the same properties as understood in material science and other disciplines. The TPA parameters are supposedly objective measures of the tested food's textural attributes. But because they are all specimen size-dependent, they cannot be considered intensive material properties. Also, because the arbitrary test conditions, notably the specimen and probe's geometries and the set deformation level significantly affect the TPA parameters' magnitudes, assigning them textural term leads to logical inconsistencies, making their relationship to the food's actual properties even more difficult to establish. It is doubtful that the instrumental TPA parameters indeed describe the same properties in different foods and sometimes even within the same food, as in ripening juicy fruits and certain soft cheeses. It is proposed that the TPA parameters currently in use be replaced by a list of mechanical and other physical properties determined by testing methods recognized by material scientists, such as "yield stress," "strain at failure," "stiffness," and "toughness," perhaps supplemented by a quantitative measure of "juiciness" and/or the acoustic signature's features, especially developed for the particular food. It is also proposed that instead of correlating such intensive material properties with sensory evaluations described by a predetermined sensory vocabulary, they should be used to study the *distribution* or *spectrum* of humans' verbal responses, expressed in their own chosen terms.

KEYWORDS

compression, mechanical properties, sensory terminology, testing machines, TPA, uniaxial deformation

1 | INTRODUCTION

The concept of texture profile analysis and its instrumental version, widely known by its acronym TPA, need no introduction to the *Journal of Texture Studies*' readers. Suffice it to say that a Google Scholar search at the time these lines were written had rendered more than 17,000 results, over 7,000 of them in the last 5 years. From its inception in the 1950s and adaptation in the 1960s to its implementation with universal testing machines (UTM), the "two bites" test has been predominant. Its "Instron version" which can be performed with any commercial UTM has caught the fancy of food scientists and technologists around the world and been applied to numerous solid foods of almost every kind. A brief history of the method's development, accompanied by historic pictures of the original instruments and of its two most notable developers the late Dr. Alina S. Szczesniak of General Foods (GF) Corporation and the late Professor Malcolm C. Bourne of Cornell can be found at http://texturetechnologies.com/resources/texture-profile-analysis, together with a variety of TPA graphical records encountered in food testing. Nowadays, the instrumental TPA is part of the "repertoire" of commercial mechanical testing equipment, which is sold with accompanying software for use by the food industry, and in research laboratories in academia and other institutions.

For any testing method, whose use has been spreading for well over half a century, all the above is a hallmark of great success. Indeed, Szczesniak, Friedman, and their colleagues at the Massachusetts

This article was published on AA publication on: 04 February 2019

Institute of Technology (MIT) and GF have been and should be always remembered as pioneers in the field of Texture Studies. Their most notable and lasting contribution has been the replacement of the single point measurements of their era, such as those obtained with a hand held penetrometer, with a multiparameters "textural profile," produced and recorded by a testing machine. One of the earliest attempts in texture profiling was an instrument whose probe was a pair of human-like jaws with teeth, moving in a manner that imitates a person biting into and masticating of a real food. The device dubbed "Strain Gage Denture Tenderometer" was constructed at the MIT in the mid-1950s of the last century. Later, in the early 1960s this "Tenderometer" with its "human-like jaws" was replaced by the "General Foods Texturometer," which was based on the same idea of attempting to imitate biting into a food and its mastication, but operated with a probe having a much simpler geometry.

In a celebrated paper of this era, Bourne (1968) reported the implementation of the "two bites" idea by imposing two successive compression cycles on cylindrical pear flesh specimens mounted on an Instron Universal Testing Machine. The force–time curve obtained in this double uniaxial compression mode was recorded on a paper chart and the plot's various features were assigned sensory terms, see below.

Replacing the custom-built GF-Texturometer, which only few institutions could afford, by a standard commercial testing machine opened the way for the method's use to expand, and expansion, which has continued to this date. In the Instron TPA version, the tested cylindrical food specimen which is easy to prepare using a cork borer, or a cubic specimen which is also easy to prepare, is placed on the machine's bottom plate and compressed twice with a parallel plate mounted on the descending crosshead. This arrangement has simplified both the test geometry and the specimen's preparation procedure considerably, which has contributed to the method's popularity in food research and product development. Also, the replacement of the complicated motion of the GF Texturometer's probe by a controllable constant crosshead speed, has facilitated studies of the displacement (deformation) rate's effect on the TPA parameters, see below, or other rheological characteristics of viscoelastic foods.

When judging these early experiments, we should keep in mind that in the late 1950s and early 1960s of the 20th century, recorders having a mounted a pen and continuously moving paper chart had just started to replace manual measurements in mechanical testing. This was considered a great *improvement* at the time, which a reader of the current digital age might find hard to believe. One should also keep in mind, that food research and material science then were totally separated disciplines with very few if any contact points between them. (Agricultural engineering, which primarily dealt with the mechanical properties of crops, was perhaps a borderline exception.) The same is even truer of disciplines such as linguistics, and the neurological sciences that investigate the structure and operation modes of mechanoreceptors, the mechanisms of stimuli sensation, the information coding and its transmission to and translation into perceived properties in the brain. Obviously, the accomplishments of these disciplines are very relevant to the relation between mechanical characterization and texture perception. Nevertheless, what follows will focus almost exclusively on the narrow technical/methodological aspects of the instrumental TPA when performed with a Universal Testing Machine as has been widely practiced in Food Research in the last decades.

Not being a material scientist myself, I can only surmise how a professional rheologist might view the instrumental TPA and its applications in foods' texture characterization. Yet, I am almost certain that any material scientist from outside the food area who learns about the method will raise several troubling questions concerning its validity. At least some of these questions will most probably be the same ones that have induced me to write this article. Let me state at the outset that this essay presents a personal view, which need not necessarily represent that of the University with which I am affiliated or any other institution for this matter. The expressed ideas are not new and I have expressed them in various forms; orally, in writing under my name (e.g., Peleg, 1983, 2006), and as a publication referee for several food science and engineering journals. My main purpose in this article is to alert those in the Food Science community interested in texture evaluation by instrumental methods to issues that I consider critical to this field's health. I hope that raising them again will result in a more critical assessment of the literature on the subject. And more importantly, I hope that the open discussion of these issues will encourage researchers in the field to develop what I think is a much needed coherent testing methodology and new ways to interpret the information that it will create.

2 | SENSORY AND MATERIAL SCIENCE VOCBULARIES

2.1 | Definitions of material properties

According to the International Union of Pure and Applied Chemistry (IUPAC), see Wikipedia, "an intensive quantity is one whose magnitude is independent of the size of the system whereas an extensive quantity is one whose magnitude is additive for subsystems."

To clarify, mechanical properties such as strength, hardness, elasticity, plasticity, and brittleness, see below, are all *intensive material properties*, that is, they are independent of an object's size. Examples of other intensive physical properties are density, color, and melting point. In contrast, properties such as force, length, volume, mass, and energy are all size-dependent and hence classified as *extensive properties.*

Apparently never explicitly stated in this terms, it has been taken for granted, that the purpose of the instrumental TPA has always been to measure intensive material properties, which its parameters naming clearly indicates. In other words, the distinction between extensive and intensive properties is not always maintained in the definitions used in sensory textural evaluations despite that the unstated goal is to quantify the intensive mechanical properties of foods, not those restricted to the individual tested specimens.

2.2 | The instrumental TPA and its terminology

The historic typical TPA curve recorded by the GF Texturometer is shown in Figure 1, and that of pear flesh obtained by the "Instron version" in Figure 2. The first figure depicts a force–time relationship of two successive pre-failure "bites" obtained with a tilted cylindrical

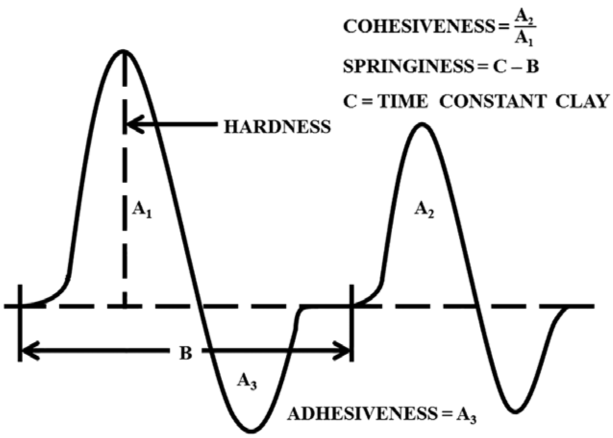

FIGURE 1 Typical instrumental TPA force–time record obtained with the General Foods Texturometer as presented in Friedman, Whitney, and Szczesniak (1963)

probe moving in a circular pattern. The second figure depicts a specimen's force–time relationship (labeled force–deformation relationship) in a double uniaxial compressive test performed with two parallel plates at a constant linear displacement (deformation) rate. In the first cycle, the specimen continued to be compressed after yielding to a set displacement, and then its remnants were compressed again after the crosshead had been (rapidly) withdrawn, see below. Despite that the curves were recorded under very different test conditions from those in the GF Texturometer, their features are described in very similar mechanical/textural terms, implying that they are the same objective measures of the corresponding material properties.

The very notion that a point on a raw force–time or force–displacement curve, an area that such a curve encloses or ratios of such areas, can be assigned a material property raises serious methodological issues to which we will return. Suffice it is to state here that none of the textural/mechanical terms defined by either version of the instrumental TPA is equivalent to the same or similarly called physical property as understood in material science, mechanics, and related disciplines.

Here is a list of examples of what the TPA terms mean outside the field of Food Science:

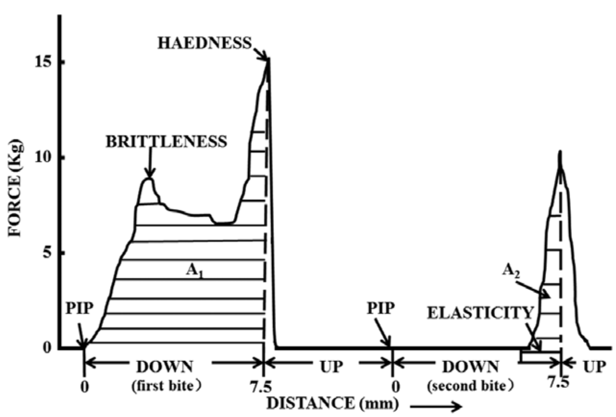

FIGURE 2 Instrumental TPA force–time (labeled distance) record of a pear's flesh obtained with the Instron Universal Testing Machine as reported by Bourne (1968)

2.2.1 | Hardness

The resistance of metal to penetration by a pressed hard metal ball (Brinell), a pointed diamond cone (Rockwell) or pyramid (Vickers), determined by the indentation size after the load removal (plastic deformation). Due to their elasticity or viscoelasticity, rubbery materials are tested differently with a "durometer" (Shore hardness).

A different definition of "hardness" refers to which other minerals a given mineral can scratch. It is expressed in the Mohs scale where diamond has the value of 10, the hardest, and talc 1, the softest. In none of the above methods is "hardness" defined in the same way as in the instrumental TPA, regardless of its version.

2.2.2 | Brittleness

The tendency of a material to shutter or break after a very small deformation, notably glass. Fragile dry cereals and snacks are familiar food examples. This is a qualitative property and certainly *does not* have force dimensions and units as in the instrumental TPA, and the same can be said about the term "fracturability" which has replaced it.

2.2.3 | Adhesiveness

Adhesion of materials to *other materials'* surfaces (e.g., glues) is usually determined by a *peel test*. It refers to the strength of the physical attraction between different materials (unlike *cohesion* that refers to the attractive forces within the same material which keep it together).

2.2.4 | Cohesiveness

Cohesion in soil mechanics and powder technology is defined at the shear stress under zero normal stress. It has stress (pressure) dimensions and units and is not a ratio of areas.

2.2.5 | Elasticity

The tendency of an object to return to its original shape after deformation. The degree of elasticity can sometimes be quantified in terms of the *recoverable strain* or *recoverable work per unit volume* vis-à-vis the total or irrecoverable (permanent, plastic) strain or work. It is *not* synonymous with the instrumental TPA "springiness."

2.2.6 | Gumminess

In the sense of a material being both sticky and having high viscosity is not recognized as a well-defined physical property outside the food literature.

2.2.7 | Chewiness

In the sense of "a measure of the energy required to chew a solid food to the point adequate for swallowing and is the product of gumminess and springiness" is not recognized as a well-defined physical property outside the food literature according to Science Direct.

For comparison, listed below are selected mechanical properties used in material science and their dimensions. They are all derived from the *stress* versus *strain relationship* (not the force vs. time or absolute deformation) and are hence inclusive material properties. Stress is a measure of the force *per unit area* (pressure units) and the strain, the relative deformation, is dimensionless.

2.2.8 | Stiffness

The resistance to deformation. Quantified by the *modulus*, the slope of the stress–strain curve at its pre-failure region, which has the dimension of stress divided by the dimensionless strain and hence of *pressure.*

2.2.9 | Strength

The stress at which a material yields or breaks in tension, compression, or shear. Strength has *stress dimensions and pressure units*. Notice that the three types of strength are *usually not the same*, and that a specimen under uniaxial deformation can and frequently fails *in shear*, and in bending *in tension.*

2.2.10 | Toughness

The amount of mechanical energy a material can absorb before its failure. Measured by the areas under the *stress* versus *strain* curve up to the yield stress. It has the dimensions of *work per unit volume.*

2.2.11 | Ductility

In metals and polymers, primarily in tension, the ability of the material to stretch and sustain plastic deformation prior to its failure. Measured as % strain at failure (dimensionless).

The two lists makes it obvious that whatever the TPA terms mean to food scientists, their definition, method of determination, dimensions, and units will be totally alien to most if not all practicing rheologists and engineers outside food research. The question that arises is whether these TPA terms are meaningful even within the restricted context of food texture evaluation?

3 | WHY CANNOT THE TPA PARARAMETERS QUANTIFY ACTUAL TEXTURAL PROPETIES

The numerous published reports on the instrumental TPA use to characterize solid foods notwithstanding, it cannot be recognized as a coherent method. This is because the instrumental TPA in all its varieties has several fundamental flaws, each sufficient for its abandonment. Here are some:

3.1 | Mechanical issues

Let us return to the first two figures. The first, Figure 1, shows a schematic or typical "two-bites" force–time record obtained with the GF Texturometer where the plunger enters/deforms the cylindrical food specimen at an angle. The plunger's motion is designed to imitate mastication and is driven by a rotating mechanism. The second, Figure 2, also shows a "two-bites" force–time record, albeit which has been obtained in uniaxial compression at a constant displacement rate (constant crosshead speed). In the shown figure, the abscissa is mislabeled. In fact the raw curve should have been the force–deformation relationship recorded with the same crosshead's speed in both directions, that is, during the "down-stroke" and "up-stroke." Had this been done (Peleg, 1976), the curves would have had the shapes shown schematically in Figure 3.

The first issue which is raised by both versions of the instrumental TPA is that all the supposedly material properties are quantified in

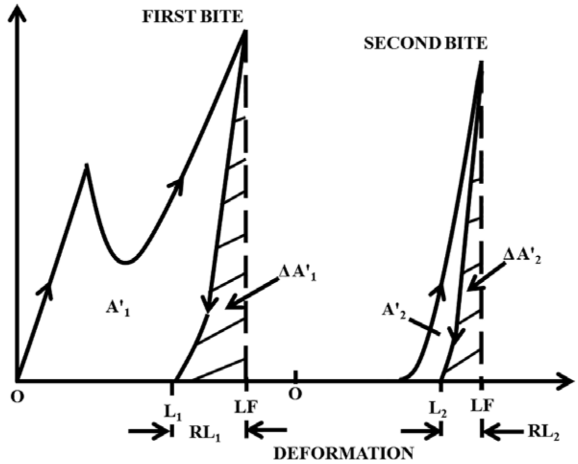

FIGURE 3 Schematic view of an instrumental TPA record when the abscissa is the displacement (deformation) instead of time. Notice that the recoverable work in the two "bites" ($\Delta A_1'$ and $\Delta A_2'$) and irrecoverable work (A_1' and A_2') have meaning only when the crosshead's velocity is the same in both directions. The total work in each "bite" is $A_1' + \Delta A_1'$ and $A_2' + \Delta A_2'$. From Peleg (1976)

terms of forces or derived from the areas under a force–time or force–displacement curve. This is not a trivial issue because in the GF version the TPA areas have mass × length × time^{-1} dimension, that is, momentum dimensions and units, while in the Instron version of force × length dimension, that is, work (energy) dimensions and units. (For a complete list of the Insrton TPA parameters' dimensions, see Pons & Fiszman, 1996.) Needless to say no real material property can have the same mechanical property having different dimensions. But more importantly, as the recorded forces strongly depend on the specimen's diameter, aspect ratio, friction with the plates (e.g., Chu & Peleg, 1985) and other factors, such as the strain rate history during the test, the TPA method if taken seriously, would imply that specimens of the same food having a different size and geometry must also have different mechanical properties or texture, which is absurd. (The above statement refers to bite size specimens. A very thin slice of cheese or sausage, say, may well have different mechanical response to imposed deformation due to its geometry a phenomenon akin to buckling.) Moreover, changing the specimen's diameter, for example, can result in a different ratio between what are supposed to be objective material properties. An extreme example is the first bite's record of ripe watermelon's flesh shown in Figure 4. If the measured yield force is seriously considered being the watermelon's "fracturability" (or "brittleness") and the force at 75% deformation its "hardness," then a specimen of the same watermelon flesh has a much higher "hardness" than "fracturability" if its diameter is 22 mm and about the same "hardness" and "fracturability" if its diameter is only 13 mm, which is of course also absurd. Similar observations concerning the set deformation level on the TPA parameters (labeled "degree of compression") were reported by Alvarez, Canet, and Lopez (2002).

The counter argument that the method is only intended for comparisons and therefore should be applied under "standardized conditions" (particularly with regards to the chosen specimen's shape, the set deformation and crosshead's speed) does not hold water. This is for the simple reason that different standardized test conditions, particularly the set

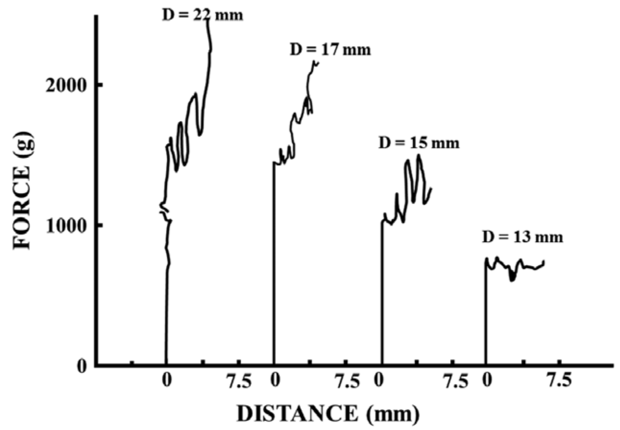

FIGURE 4 An extreme example (ripe watermelon flesh) of how the choice of the tested cylindrical specimen's diameter can affect the ratio between the TPA parameters, which supposedly represent material properties and hence size independent. The specimens' height was 10 mm. From Peleg, Gomez Brito, and Malevski (1976)

final specimen's height for the first and second bites, can alter the comparison results by affecting what are supposed to be characteristic material properties. In other words, unless the textural differences between the samples are so large so that *every method* will distinguish between them (making the tests superfluous…), a "harder" food material as found in one test geometry can at least in principle come out "softer" under a different set of "standard test conditions." For example, the same constant crosshead speed in the TPA's Instron version produces different strain-rate histories in specimens having different heights (Peleg, 1987). (For the variability in individual humans' measured chewing velocities, see e.g., Meullenet, Finney, & Gaud, 2002.)

The already mentioned crosshead's return speed, which determines the areas A_1 and A_2, has been frequently uncontrolled. However, this is not a minor issue because its setting strongly affect what is called "cohesiveness" which again, is supposedly a material property. If one tries to determine the recoverable work as shown in Figure 3, preferably in the pre-failure deformations range, then the return speed ought to be the same as in the down stroke as already stated. Also, setting the displacement to 70, 75, or 80% of the specimen height, for example, will frequently result in very different degrees of "hardness." And consequently, because of the stroke's length effect on the areas A_1 and A_2 it will also result in different degrees of "cohesiveness" as has been documented by Alvarez et al. (2002) and Rosenthal (2010).

The so-called "adhesion" is defined by A_3, the area above the curve during the up-stroke. As the area A_2, its magnitude is primarily determined by the crosshead's return speed, and also by how much of the specimen's remnants (after the first bite) remain attached to the plates. As different foods fail or compress differently, for example, peach flesh versus marshmallow, and because the actual adhesion also depends on whether the probe is made of metal or Teflon, for example, what the area A_3 actually means is not at all clear. And here again, a wider specimen is very likely to be found more adhesive, which makes little sense.

The universal TPA terms assigned to the various parts of the pre- and post-failure force–time or force–displacement curve can be also challenged from a different angle. A notable textural manifestation of ripeness in many but not all fruits is that they become not only sweet but also "juicy." Thus in an unripe fruit flesh (which frequently fails in shear), the post-yield compressive force tends to rise due to the resistance of the still intact parts of the fractured specimen. In contrast, in a ripe juicy fruit the post-yield deformation can be viewed as juice expression, which can be monitored by weighing the expelled liquid (Peleg et al., 1976). Thus, the notion that the same TPA parameters are applicable to ripening mangoes or peaches and to bananas or avocados ought to be viewed with caution.

All this brings us to a fundamental semantic issue. One can claim that many if not all descriptive terms only have contextual meaning; the "hardness" of a hard-boiled egg is not "the same" as that of a hard exam and heavy cream is actually *lighter* than light cream when it comes to density (Peleg, 1983—I will be glad to e-mail the cited paper's reprint to readers who have difficulty downloading it directly form the Internet). If the notion that descriptive terms have a meaning only contextually is true, then it is doubtful that there is such a thing as universal textural scales applicable to all solid foods. If there were, which is highly doubtful, one would still have to demonstrate that all psychophysical relationships obtained from testing individual foods separately, all fall on a single Universal curve. In other words, one would be able to show that "hardness" of a cheese cube, say, is perceived in exactly the same manner as in a hazel nut, see below.

But even in a more restrictive sense, one can legitimately doubt that any of the listed TPA parameters has the same meaning in a juicy fruit such a pear or mango, or a soft cheese, such as brie or camembert, at different stages of ripeness, regardless of the mechanical protocol used for their instrumental determination. A related issue is whether sensory textural attributes as perceived in the mouth (assumed to include acoustic) can really be perceived in isolation, that is, separately from chemical, thermal, and other stimuli. The same could probably be said about sensing with the fingers where differences in heat transfer coefficients may provide a clue. If textural properties cannot be sensed in isolation, then different degree of ripeness, at least in the above examples, should be treated as different foods to which the commonly used scales may not apply.

3.2 | Calibration of the TPA sensory scale with different foods

The introduction of the TPA method can be traced to the seminal and very influential paper of Szczesniak, Brandt, and Friedman (1963). The group reported five smooth correlations between the instrumental parameters obtained with the GF Texturometer described by Friedman et al. (1963), which replaced the MIT Strain Gage Denture Tenderometer, and their corresponding sensory evaluations. An additional correlation was reported between perceived viscosity and that measured with a Brookfield viscometer. With the exception of "gumminess" which was determined in a tablespoon of flour pastes at five different concentrations, all the other correlations were obtained from tested samples of 5–9 different foods most but not all of them having exactly the same size and morphology. All the reported correlations had the general shape shown schematically in Figure 5 with the axes reversed that is, presented in the form of instrumental parameters versus sensory evaluations. Such reported results, see also Meullenet et al. (2002) on imitative testing, and Kramer and Szczesniak (1973), raise at least two critical issues:

As already mentioned in the previous section, the instrumental TPA "hardness," for example, is expressed in force units and hence its

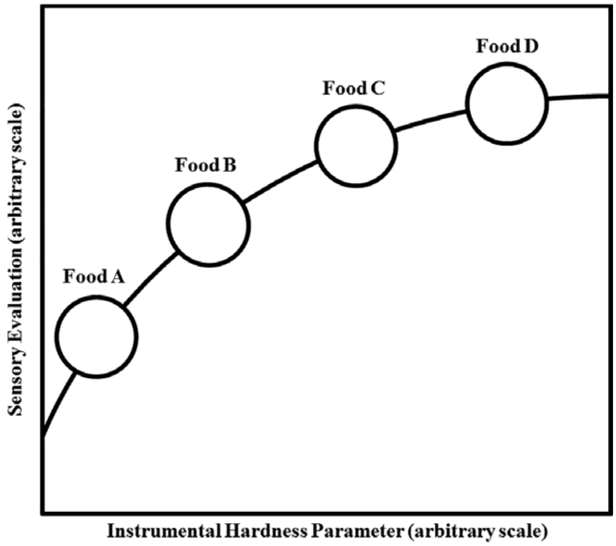

FIGURE 5 Hypothetical correlation between instrumental and sensory TPA parameters obtained from different foods. (After Szczesniak et al., 1963)

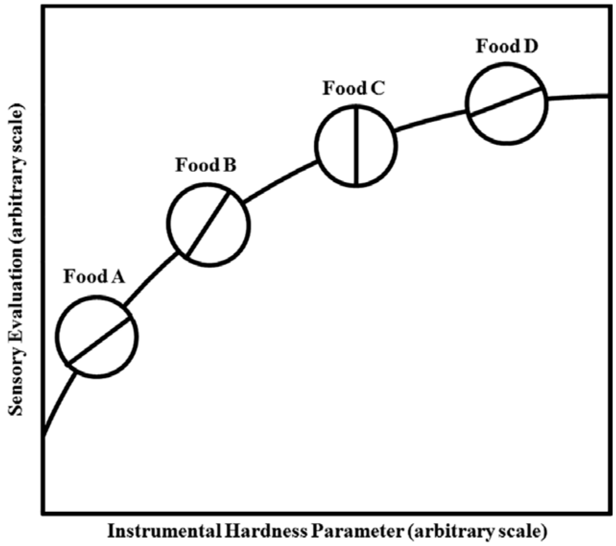

FIGURE 6 Using Figure 5 to demonstrate that a correlation between instrumental and sensory parameters obtained by from different foods need not be applicable to any particular food. (Adapted from "On fundamental issues in texture evaluation and texturization" by M. Peleg, 2006, Food Hydrocolloids, 20, pp. 405–414)

magnitude inherently depends on the probe's and specimen's size and shape and also on the set displacement level and other factors. The same can be said about the other parameters (Alvarez et al., 2002). It is, therefore, unclear whether such smooth correlations between instrumental and sensory parameters can also be reproduced with different foods, specimen geometries and test conditions, to justify the same terminology especially when used in the Instron TPA version. Moreover, the usefulness of a correlation between *almost any* instrumental mechanical parameter and a sensory attribute based on different foods can be challenged on the grounds that if the textural differences between these foods are sufficiently large, a correlation of sorts will always emerge. In other words, one does not need and instrument, especially a sophisticated one, to distinguish between an apple and marshmallow or even between cream cheese and cheddar cheese. The relevant question is whether the method is sensitive and consistent enough to distinguish *between samples of the same food* and whether humans can detect these differences in the same manner. As shown schematically in Figure 6, it is the author's opinion that unless proven otherwise, "there is no reason to assume that the relationship between any sensory attribute of a given food and a particular instrumental textural parameter must be the same as the relationship between that attribute and that particular instrumental parameter obtained by testing different foods" (Peleg, 2006). If correct, using a correlation derived from the instrumental TPA of brie, cheddar, and hard parmesan, for example, is very unlikely to be found useful to predict the sensory response to even these cheeses when produced on different dates or in different locations, during their aging or storage, and so forth. It will be even less likely that such a correlation will be useful if obtained from cream cheese, frankfurters, olives, and carrots.

4 | WHAT IS THE ALTERNATIVE?

The idea that the texture of solid (and semisolid) foods should be characterized by a profile consisting of several properties can be maintained if these are all intensive material properties, that is, defined and determined in ways that guarantee their size independence. The first step therefore is to drop the idea that "standard testing conditions" resolves the size issue, and extract the mechanical properties from stress–strain relationships. As we are dealing with large deformations, constructing a meaningful stress–strain relationship is not as the straightforward step of dividing the force by the initial specimen's cross-sectional area and the displacement (deformation) by the initial specimen's length, see Peleg (1987) for a detailed explanation. The same can be said about the *strain rate*, which at constant displacement rate *varies with the compressed specimen's height* (ibid). A yield *stress* is an intensive material property and so is the area under a stress–strain curve, which has energy per volume dimension and units. The area under the curve prior to yielding is known as *toughness*, as already mentioned, and is also an intensive material property. In highly viscoelastic materials, the measured properties *strain rate-dependence* can be viewed as a material property by itself. The *strain at failure* is a material property and so is the *modulus of deformability*, which for large deformations is calculated after conversion of the experimental force–displacement curve into corrected ("true") stress–strain relationship (Peleg, 1987). In nonelastic foods, the modulus of deformability is *not* synonymous to the Young modulus, which in engineering materials is determined from small elastic deformations. The *failure pattern* is a material property although its objective characterization can be a challenge. In some cases, a true size dependence, that is when observed after the conversion to stresses and strains, can be treated as a material property in itself. The above list is by no means all-inclusive. But such properties will be recognized by any material scientist and will have universal meaning even if new terms will be needed to describe them.

Another suggestion, which most probably will be even more controversial is to abandon the traditional correlation route altogether and replace it with a different new methodology. What is proposed is to start by determining the mechanical and other relevant physical properties of foods by methods developed in or understood by material science. Once determined, the food will be given to a panel, professional or made of potential consumers, and the experimenter records the *frequency distribution* or *spectrum* of the individuals' verbal characterizations in (sensory) terms such as "hard," "rubbery," "chewy," or whatever. The panelists can be assisted by a list of suggested terms from which they can choose with or without quantifiers. The analysis might reveal how specific objective mechanical properties are actually perceived by actual humans and to which of them they are most sensitive. The properties need not be solely or purely mechanical, or defined by a single parameter. They may include liquid release pattern, melting point profile, and an acoustic signature's features. It is doubtful that a methodology of this kind will be adopted any time soon. One of the reasons is that the software to process the data that such a method will produce is yet to be written. If the concept is ever implemented, writing the program need not be a too complicated task for a professional programmer who could utilize existing commercial data processing software. But even if only its first part is implemented, that is, moving from the instrumental TPA parameters to true (intensive) material properties will be a step forward and relieve the currently used method of its inherent inconsistencies.

4.1 | Future challenges

The original developers of the instrumental TPA correctly introduced the idea that during mastication, the mechanical stimuli, which humans perceive as "texture," include several that are generated in the food's post-failure deformation regime. Failure (fracture), post-failure mechanics, and mastication dynamics (Chen, 2009) are fields having a rich body of knowledge. A major challenge to food scientists and engineers interested in the mechanical characterization of foods, as I see it, would be how to implement this accumulated knowledge in textural evaluation, and identify what new knowledge needs to be created to develop a coherent method or methods to account for foods' pre- and post-failure deformations. Whatever future research will produce, it will also have to account for the roles of not-strictly mechanical phenomena, such as moisture and flavor release, melting, sound emission, and so forth. This research will also have to deal with the differences in the *sensitivity* between humans and machines, and the inherent variability of individual humans and probably human groups, classified by age and ethnicity, for example, and other criteria. Certainly, the task will not be easy and may involve what is known as "big data." But surely such research will be an exciting endeavor to those interested the field's development.

ETHICAL STATEMENTS

Conflict of Interest: The author declares that he does not have any conflict of interest.

Ethical Review: The study did not involve any human or animal testing and the manuscript needs no institutional approval.

Informed Consent: The author solemnly declares that being the sole author of the work he needs no informed consent from any (non-existing) coauthors.

ORCID

Micha Peleg https://orcid.org/0000-0002-4041-3892

REFERENCES

Alvarez, M. D., Canet, W., & Lopez, M. E. (2002). Influence of deformation rate and degree of compression on textural parameters of potato and apple tissues in texture profile analysis. *European Food Research Technology*, *215*, 13–20.

Bourne, M. C. (1968). Texture profile of ripening pears. *Journal of Food Science*, *33*, 223–226.

Chen, J. (2009). Food oral processing—A review. *Food Hydrocolloids*, *23*, 1–25.

Chu, C. F., & Peleg, M. (1985). The compressive behavior of solid food specimens with small height to diameter ratios. *Journal of Texture Studies*, *16*, 451–464.

Friedman, H. H., Whitney, J. F., & Szczesniak, A. S. (1963). The Texturometer—A new instrument for objective texture measurement. *Journal of Food Science*, *28*, 390–396.

Kramer, A., & Szczesniak, A. S. (1973). *Texture measurements of foods: Psychophysical fundamentals; sensory, mechanical, and chemical procedures, and their interrelationships*. Netherlands: Springer.

Meullenet, J. F., Finney, M. L., & Gaud, M. (2002). Measurements of biting velocities and predetermined and individual cross speed instrumental imitative tests for predicting cheese hardness. *Journal of Texture Studies*, *33*, 45–58.

Peleg, M. (1976). Textural profile analysis parameters obtained by an Instron universal testing machine. *Journal of Food Science*, *41*, 721–722.

Peleg, M. (1983). The semantics of rheology and texture. *Food Technology*, *37*, 54–61.

Peleg, M. (1987). The basics of solid foods rheology. In H. Moskowitz (Ed.), *Food texture* (pp. 3–33). New York: Marcel Dekker.

Peleg, M. (2006). On fundamental issues in texture evaluation and texturization. *Food Hydrocolloids*, *20*, 405–414.

Peleg, M., Gomez Brito, L., & Malevski, Y. (1976). Compressive failure patterns of some juicy fruits. *Journal of Food Science*, *41*, 1320–1324.

Pons, M., & Fiszman, S. M. (1996). Instrumental profile analysis with particular reference to gelled systems. *Journal of Texture Studies*, *27*, 597–624.

Rosenthal, A. J. (2010). Texture profile analysis—How important are the parameters? *Journal of Texture Studies*, *41*, 672–684.

Szczesniak, A. S., Brandt, M. A., & Friedman, H. H. (1963). Development of standard rating scales for mechanical parameters of texture and correlation between objective ad sensory method of texture evaluation. *Journal of Food Science*, *28*, 397–403.

How to cite this article: Peleg M. The instrumental texture profile analysis revisited. *J Texture Stud*. 2019;1–7. https://doi.org/10.1111/jtxs.12392