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ABSTRACT: Texture is a major aspect of food. The texture of food encourages the consumer to buy certain products again and again. The quality of food is influenced by its textural properties of food. Hardness, adhesiveness, and cohesiveness are some major textural parameters of food. Texture analysis takes a prominent role in analyzing textural parameters, which helps to assess the quality of food. The "Texture profile analysis" is used to analyze the textural properties of food. This method is also known as the double compression test. In the TPA instrument, probes are a major part that makes contact with food and returns to the original position at a specific speed. There are various applications of TPA in the food industry. The uniformity in the texture is Analysed with help of a TPA instrument. Analyzing textural properties from sensory panels is time-consuming but the TPA instrument saves time and gives the accurate result with a typical graphical presentation. The TPA has major applications in research and development and the quality section of the food industry. In this review, the TPA method is discussed along with the textural parameters of the products.

KEY WORDS: Texture, Texture profile analysis, Sensory analysis, probes, Applications, Food

INTRODUCTION

The food texture is a sensory property that is sensed with the help of vision, hearing, touch, and kinesthetics. In recent years scientists tried to relate human sensory evolution with instrumental analysis. It includes texture profile analysis and shear analysis. The textural properties of food depend upon the molecular arrangement and the material present inside the cell wall changes during handling, processing, and storage. The texture is a sensory property derived by human beings as well as instruments. Texture gives proper orientation to research. (Szczesniak, 2002). The word texture is derived from the word “Textura”. Humans need a variety of textures for example potato chips need a crispy texture tested by acoustic force test. If it doesn’t meet the consumer requirement it will be rejected. Tenderness is one of the textural properties which derives freshness. The food texture can also be termed energy metabolism. Previous research has shown that the soft texture of food products is responsible for type 2 diabetes. Food texture does not contain sense and taste. (Liu et al., 2019).

BACKGROUND OF TEXTURE PROFILE ANALYSIS

The classification of textural property is given by szczensniak’s which is the factor between the instrumental and sensory evolution of the food. In the instrumental texture profile analysis, the General food texturometer was used by szczensniak for the research. This instrument is the modified form of the MIT Denature tedorometer which is used to mimic the mastification action of the mouth and its unit is composed of flexible arm, strain gauge, and plunger which act upon the food sample. In this equipment, the force is generated through strain gauge which is recorded on the strip recorder. The size of the plunger differs according to the food sample. The height of the plunger is 2.5 cm and the material used for the plunger were luctile, aluminium and brass. GF texturomeater generates the plot which represented as the force as function of the time. The results obtained in the form of texturomeater curves were interpreted on the base of the mechanical properties classified by szzeniak. The seven textural properties are provided by the curve which was named as the hardness, brittleness, cohesiveness, adhesiveness, chewiness, gumminess, and viscosity.(Pons & Fiszman, 1996)

1. Sensory perception vs Instrumental measurement

The subjective methods such as “sensory perception” used for the analysis and interpreting human response to the parameters of food and presided with help of five sense as taste, touch, smell, sight and hearing. These methods can be classified into two forms as ‘Oral’ and ‘Non-oral’, used as tool for documentation of human responses to external stimuli. In the subjective

methods trained and untrained panel members are required for the analysis of textural measurement. (Chen & Opara, 2013)

1.1 Sensory panel

The panellists are trained or semi-trained `have been trained to analyse the sensory attributes. The no. of panel members is 6 to 7 or 6 to 12 or 8 to 16 and the required members are about 10. The small group of sensory panels faces the questions like the results are statistically and scientifically reasonable or not. The level of training is described with the help of several technologies, ranging from “Expert”, “Highly experienced”, “Trained”, “semi-trained”. The age from 16 to 69 could be able to become the part of sensory panels. The untrained consumer panel consist of at least 70 panel members.(Drake, 2007)

1.2 Sensory scale

There are some common terms are used by sensory panels to describe the textural properties of food. The textual properties of potato chips are described as terms crispiness, hardness and crunchiness. These sensor scales are adopted by the researchers to characterize the food products. (Chen & Opara, 2013)

1.3 Limitations of sensory evolution

The adaption of sensory responses depends upon the degree of training given to the panel members. The human’s sensory perception depends upon the rheological properties of food and other attributes such as taste and smell. The sensory panels are somewhat similar to instruments, they require regular calibrations and maintenance. These methods in comparison to the instrumental measurement are more expensive and time consuming (Foegeding et al., 2010).

2. Instrumental measurement of food

The textural parameters of food are measured with the use of instruments in objective methods. Mechanical /rheological properties of food has significant effect on the objective methods which are used in the research. Fundamental, empirical and imitative are the three methods which are used in the instrumental testing. Fundamental tests are invented by the scientists which involves use of human senses such as mouth at the stage of mastification .(Bourne, 2002) The empirical and imitative test involves the use of instruments for analysing textural properties of food. Non-destructive and structive methods are used for analysis of fresh and processed food.(Chen & Opara, 2013)

3. Texture Measurement

Texture is an important sensory property which measured only by humans and some instrumental methods. Texture profile analysis is an instrumental method which convenient for rapid measurement of textural properties. (Nishinari et al., 2013)The subjective techniques used in texture measurement requires trained panel members, score card. These techniques are time consuming and not useful for the standardization of food products. The textural parameters are evaluated with the use of various kind of instruments in the objective measurements. These techniques are helpful to save the time as well as give precise results.(Ranganna, 1986)

The TPA test is also known as the two-bite-test or the double compression test. It mimics the action of chewing which normally occurs in mouth during mastication. The TPA test provides the complex data which includes gumminess, springiness, chewiness and adhesiveness. In the texture profile analysers, probes are a measure part which is used to make contact with the food sample. These probes have a specific speed and returns to the original position. (Srilakshmi, 2020) Table 1 reprents the different probes and their applications in food industry. General foods corporation technical centre (1963) has developed the texture profile analysis as instrument's method. Instron is one of the large instruments used to measure the mechanical properties of materials. Now a days a smaller texture analyser is developed to perform the TPA of various food products. (Trinh & Glasgow, 2012)

4.Parameters of texture profile analysis: -

In the texture profile analysis, parameter's such as hardness, adhesiveness, cohesiveness, springiness and gumminess are observed. Along with the textural parameters' compression speed, temperature and strain (the extent to which sample is compressed) have a measure role in texture profile analysis. The textural parameters differ along with the type of food products. In the liquid foods, extensional viscosity is a measure texture parameter in addition to shear viscosity. (Nishinari et al., 2013)

4.1 Hardness

Hardness is one of the major textural parameters which is measured in first compression. It is maximum peak force during the first compression. If the food product is excessive hard, it is not acceptable by the consumers. In the TPA hardness can termed as the force required for the pre-determined deformation. Sometimes recorder technology in texture analysers area unable to differentiate between peak force and fractures. (Trinh & Glasgow, 2012),

4.2 Brittleness

Brittleness is also known as the fracturability first significant break in the curve. It is the tendency of material to fracture, crumble, crack or fail to open when the small amount of force applied. In the typical TPA curve fractuability recorded as: -

- Distance to break- Fracturability/brittleness(mm)
- Force to break- hardness(g/kg)
- Gradient of slope- toughness/stiffness$(g/mm)^3$ (Srilakshmi, 2020)

4.3 Cohesiveness

It is the ratio of the area measured under second peak and the area under second peak(A2/A1). When the product adheres cohesive or tensile stress is said to be cohesive product. Cohesiveness is a strength of internal bonds of the material. Talcum powder is used to coat the sample, when the food sample exhibits the adhesiveness. It is coated before the recording the cohesiveness profile. (Rangana, 1986)In the supply chain of food products, they are subjected to various types of stresses during processing, handling and storage. If the products adhere cohesion, it can tolerate these stresses. The poor cohesion is unable to tolerate the stress. The instrumental prediction of cohesiveness is not much accurate as the hardness and springiness. (Sri Lakshmi, 2020)

4.4 Springiness

Springiness measures how the food products physical spring back to the original shape after the first compression. In the second compression, springiness is measured at the down stroke. The original name of springiness' is 'elasticity' which measures the rate of deformation of sample returns to its initial shape & size. (Trinh & Glasgow, 2012)

4.5 Adhesiveness

Adhesives measure the force required the plunger or probe the food sample.. (Ranganna, 1986)

4.6 Gumminess

Gumminess can only be applied for the semisolid foods. the product Should be semisolid and solid at the same time. The gumminess is measured as the hardness × cohesiveness (Texture Profile Analysis | Texture Technologies).

4.7 Chewiness

It can be applied to only solid products which can measured as hardness × Cohesiveness × springiness(Ranganna, 1986)

4.8 Resilience

Resilience is referred as measurement of how the sample takes its original height. Basically, it is ratio of first up decompression stroke to the first compression stroke. It is measured at the

first compression, before the wait time is started (Texture Profile Analysis | Texture Technologies).

5. Principal components of Texture profile analyser

The basic components of TPA instrument includes Force transducer (load cell and test cell), probe and the platform are provided for the sample. In the TPA instruments unique software's are used. These software's helps the instruments in setting textual parameter's, data collection and plotting a typical TPA graph. In the Texture profile analyser, force transducer moves up or down to prove a stable strength to the sample. The changes in the sample due to pressure is detected by probes and these changes are transmitted to force transducer. The texture analysers use different type of probes and fixtures depends upon type the different parameters of food texture are obtained with TPA instrument. Hardness ,factutability, Springiness ,adhesiveness, chewiness, gumminess and resilience are the measure textural properties studied in the TPA test .(Liu et al., 2019)

6. TPA Experiment Set-up

6.1 Sample preparation

For the successful texture analyses sample preparation is the critical step , where the sample should not be broken down during the TPA test. The height of the sample should be 1.3 cm and area give should be suitable for the measurement of elasticity which is 2.5 cm.(M.pons) In the TPA test , consistent preparation of sample is required to obtain a good data. For the TPA measurements cutting and slicing of samples is necessary. It helps to avoid the edge effects in the test sample. (Mochizuki, 2001)

6.2 Speed of test

The various textural properties depend upon the energy, since in the TPA graph area under the force-displacement curve represents the energy. The speed of compression and withdrawal in the TPA test will be same to compare the level of energies between the compression and withdrawal. The standard speed employed in the TPA test was 42bites per minute. (Trinh & Glasgow, 2012)

6.3 Compression distance

The distance during the compression and deformation should be taken in account. In the case of products like cheese the distance of the probe should set at 10%,40% and 60% from the original height of sample. After the first and second compression sample retains its original shape and size.(Trinh & Glasgow, 2012)

6.4 Time management

In the TPA test, time required to test one sample is approximately 5 to 10 min. It also includes the sample positioning and cleaning of the instrument before and after the experiment. For the TPA test sample preparation requires more time than the measurement. Now a days food industry offers most uniaxial instrument which is controlled by computer and it have its own software to immediately calculate the TPA parameters. (Mochizuki, 2001)

6.5 Destructive verses non-Destructive measurement

In the case of solid foods destructive methods are used to measure the textural properties of food. These methods are divided into two parts as empirical and fundamental methods. The sensory perception of the food comes under the empirical methods. In the fundamental methods, the basic mechanical properties are measured such as young modulus, poisson ratio and shear modulus. These tests are not able to interpret accurately in terms of human perception of texture. In the test like creep test, relaxation test and dynamic test are used to measure elastic properties of food. These tests are performed in direct or indirect form with the specific dimension. These tests require more time as compared to empirical test. The destructive methods involve puncture, compression, shear, twisting, tension, bending. (R.lu)

On the other hand, non-destructive methods are used to measure the textural properties of fresh and processed foods. These methods are widely used in the QC department to control the quality of products (fresh and processed foods).

7.Different tests performed under texture profile analyser

7.1 Puncture test

In the puncture test, probes are used to penetrate into the food sample. The puncture test depends upon the size & shape of the probe, type of food product and speed of loading. It is the empirical technique which involves the compression and shearing of the sample. In the case of fruits, firmness is tested using the MT firmness tester which have the hemispherical probe. It is the well-known puncture test used to measure the textural property of food. The machine controls the speed of loading and also records the results in the form of force deformation curve (Lu, 2013) Hardness of the product can be measured with the help of puncture test. For the penetration test flat ended cylinder are used to penetrate into the food sample. Some other applications of puncture test include LERA texture analyser which is used to analyse the textural properties of confectionary products, dairy products and hydrocolloid industry.(Hellyer, 2004)

7.2 Compression test

The mechanical properties of solid foods like fruits, vegetables and solid foods are measured in the compression test. The standard procedure to conduct compression test is given by "The American Society of Agricultural and biological engineers (ASABE). The intact foods are used for the compression test to calculate the elastic module form the compressive force. The uniaxial and confined tests are the two types of compression tests used to measure the textual parameters of intact foods. In the uniaxial test, the force applied on the sample in one direction and allowed to expand the sample in two directions. This method is beneficial for the foods such as the grains. In the compression tests are useful to measure the textual property of fresh and processed fruit products. (Kaszab et al., n.d.)

7.3 Shear test

The shear test can define as the act of applying force to cut down the food sample into two pieces. In the case of pure engineering, shear is difficult to perform experimentally except under torsion and special loading condition. The shear tests are used to measure the textural properties of muscle foods. In the shear test "Warner Bratzler shear tester" was recommended as standard device by American meat science association which measures the tenderness of meat products.(Lu, 2013)

7.4 Torsion test

The torsion test also known as twisting which is used to measuring textural parameters. Torsion test depends upon the shear properties of the food. During this test force is applied on the sample form the one part of the sample to another part. These test are used in solid food testing (Hamann et al., 2006).

7.5 Bending test

Food sample is measured. The tensile mechanical properties are measured in the bending test. Various food products perceive the tensile properties which differs from the compression. The tensile test is useful to study the structural changes in the muscle foods during the food processing treatments.(Lepetit & Culioli, 1994)

7.6 Three-point bending test

The samples such as the biscuits, cornflakes and crisp potato products are tested in the three-point bending test. In these tests, force is applied on the sample. These tests are commonly applied in the bakery industry (Schmilovitch & Mizrach, 2013).

7.7 Single-edge notched bend (SENB) test

For SNEB test, sample should meet the standard requirements of the geometry. In these tests, the force is applied from top to on the centre of the test strip and notch was made under slide.

Fractutability of biscuits wad measured in these tests (Schmilovitch & Mizrach, 2013). Table 2 represents the different test performed in TPA with its application in food industry.

8. Applications of TPA in the Food Industry

8.1 TPA application in sea food industry

TPA is mainly used to analyse the freshness of food products with the use instrumental tests such as puncture test, compression test, shear teat and tension test. The texture is evaluated in the form of force/defamation curve. For the fish texture measurement TPA is considered as standard test. TPA as known as double compression method give perfect information about the textural parameter's such as hardness, cohesiveness, springiness and adhesiveness (Cheng et al., 2014). In the fish products, the WB and Kramer shear compression cell-based method is used to measure the textural parameters. Springiness is one of the important textural parameters in the minced fish which depends upon the type of fish species and process of production. The type of the products, its taste. In the TPA of test of fish products (Wu et al., 2014).

8.2 TPA application in fruit and vegetable industry

There are two types quality attributes such as internal and external are considered in the case of fruits and vegetable products. The appearance, colour, size is coming under the external quality attributes. The pectin and starches are the viscous components contributes to the firm texture to the root crops and soft texture to the berries. The textural properties of fruits and vegetables are prescribed with the help of viscoelastic measurements. In the viscoelastic measurement force, deformation and time were considered were taken in count for the viscoelastic measurements. In the TPA test, speed of the test should be kept constant with keeping the record of test. Firmness is one of the important textural properties in the case of fruit and vegetables. Normally horticultural products are tested using the firmness test. Compression test and puncture test are used to measure the firmness of fruits and vegetable of products. The several types of probes are used to measure the firmness according to level of force and deformation. (Schmilovitch & Mizrach, 2013)

8.3 TPA application in the bakery industry

TPA test are commonly used to test high moisture bakery products such as muffins and cake-like products. In the TPA tests, sample are compressed twice to obtain the curve which measure the textural properties like hardness, cohesiveness and springiness. Springiness is a measure textural parameter in the case of cakes and muffins because it is used to analyse the freshness and aerated structure of muffins. During the TPA test muffins returns to its original shape after the first compression. Cohesiveness is also another measure textual property of muffins and

cakes like products. It is the energy required during the second compression in the TPA model.(Fiszman et al., 2013)

8.4 TPA application in crisp snacks and extruded products.

The crisp snacks and extruded cereal products such as crackers and cereal products are the solid food products with low moisture content. In the some extrude products water content was under of 10.(Duizer, 2013) Fractutability and crispness are studied in the case of cylindrical snacks. For pelleted and shelled snacks are tested with chewiness and WB test are used to assess the fraturability and chewiness by using the V-shaped probe.(Paula & Conti-Silva, 2014)

9. Limitations of TPA instrument

The instrumental TPA have some limitation in comparison with the sensory TPA. It includes the sensitivity and complexity. The TPA instrumental parameters are repeatable, these instrumental parameters are well correlated with the TPA sensory parameters. The instrumental TPA test is greatly depends upon the measurement conditions of plunger, the precise sample shape and skilled person to operate the instrument (Mochizuki, 2001).

Conclusion

These instrumental TPA methods comes under destructive methods which can correlated with the sensory perceptions. The instrumental texture profile analyses are efficient then the humans' sensory perceptions which requires more time and money. The main objective of these instrumental method is to analyse and monitor the quality of the food products from the production to distribution. Probe is one of the major parts of the texture profile analysis instrument. There are various types of the probes and fixture are available in the market which can be used according to the type of product. In the TPA test various parameters of the product are studied to interpret the quality of product. Different types of tests such as puncture test, shear test, three-point bending are performed on the basis of types of food product. In the texture profile analysis, skilled personalities to set the experiment and for interpreting the results of the test.

REFERENCES:

Adhikari, K., Heymann, H., & Huff, H. E. (2003). Textural characteristics of lowfat, fullfat and smoked cheeses: sensory and instrumental approaches. *Food Quality and Preference*, *14*(3), 211-218.

Appelqvist, I. A. M. (2013). In-mouth measurement of food quality. *Instrumental Assessment of Food Sensory Quality*, 255-283.

Bourne, M. (2004). Relation between texture and mastication. *Journal of Texture Studies*, *35*(2), 125-143.

Bourne, M. C. (2002). Chapter 7-Sensory Methods of Texture and Viscosity Measurement. Food Texture and Viscosity.

Bourne, Malcolm. (2002). CHAPTER 3. Principles of Objective Texture Measurement. 10.1016/B978-012119062-0/50004-8.

BREUIL, P., & MEULLENET, J. F. (2001). A comparison of three instrumental tests for predicting sensory texture profiles of cheese. *Journal of Texture Studies*, *32*(1), 41-55.

Cavitt, L. C., Meullenet, J. F., Gandhapuneni, R. K., Youm, G. W., & Owens, C. M. (2005). Rigor development and meat quality of large and small broilers and the use of Allo-Kramer shear, needle puncture, and razor blade shear to measure texture. *Poultry science*, *84*(1), 113-118.

Chauvin, M. A., Ross, C. F., Pitts, M., Kupferman, E., & Swanson, B. (2010). Relationship between instrumental and sensory determination of apple and pear texture. *Journal of Food Quality*, *33*(2), 181-198.

Chen, J. (2007). Surface texture of foods: Perception and characterization. *Critical reviews in food science and nutrition*, *47*(6), 583-598.

Chen, J., & Stokes, J. R. (2012). Rheology and tribology: Two distinctive regimes of food texture sensation. *Trends in Food Science & Technology*, *25*(1), 4-12.

Chen, L., & Opara, U. L. (2013). Texture measurement approaches in fresh and processed foods—A review. *Food research international*, *51*(2), 823-835.

Cheng, J. H., Sun, D. W., Han, Z., & Zeng, X. A. (2014). Texture and structure measurements and analyses for evaluation of fish and fillet freshness quality: a review. *Comprehensive Reviews in Food Science and Food Safety*, *13*(1), 52-61.

Cheng, J. H., Sun, D. W., Han, Z., & Zeng, X. A. (2014). Texture and structure measurements and analyses for evaluation of fish and fillet freshness quality: a review. *Comprehensive Reviews in Food Science and Food Safety*, *13*(1), 52-61.

Civille, G. V., & Oftedal, K. N. (2012). Sensory evaluation techniques—Make "good for you" taste "good". *Physiology & Behavior*, *107*(4), 598-605.

Di Monaco, R., Cavella, S., & Masi, P. (2008). Predicting sensory cohesiveness, hardness and springiness of solid foods from instrumental measurements. *Journal of Texture Studies*, *39*(2), 129-149.

Drake, M. A. (2007). Invited review: Sensory analysis of dairy foods. *Journal of dairy science*, *90*(11), 4925-4937.

Duizer, L. M. "Measurement of the texture of dry crisp products." *Instrumental Assessment of Food Sensory Quality*. Woodhead Publishing, 2013. 403-419.

Fiszman, S. M., Sanz, T., & Salvador, A. (2013). Instrumental assessment of the sensory quality of baked goods. In *Instrumental assessment of food sensory quality* (pp. 374-402). Woodhead Publishing.

Foegeding, E. & Çakır, Esra & Koç, Hicran. (2010). Using dairy ingredients to alter texture of foods: Implications based on oral processing considerations. International Dairy Journal. 20. 562-570. 10.1016/j.idairyj.2009.12.013.

Friedman, H. H., Whitney, J. E., & Szczesniak, A. S. (1963). The texturometer—a new instrument for objective texture measurement. *Journal of Food science*, *28*(4), 390-396.

Fundo, J. F., & Silva, C. L. (2018). Microstructure, composition and their relationship with molecular mobility, food quality and stability. In *Food Microstructure and Its Relationship with Quality and Stability* (pp. 29-41). Woodhead Publishing.

HAMANN D D, ZHANG J, DAUBERT C R, FOEGEDING E A and DIEHL K C (2006), 'Analysis of compression, tension and torsion for testing food gel fracture properties', J Texture Stud, 37, 620–639

Hamann, D. D., Zhang, J., Daubert, C. R., Foegeding, E. A., & Diehl Jr, K. C. (2006). Analysis of compression, tension and torsion for testing food gel fracture properties. *Journal of Texture Studies*, *37*(6), 620-639.

Harker, F. R., Maindonald, J., Murray, S. H., Gunson, F. A., Hallett, I. C., & Walker, S. B. (2002). Sensory interpretation of instrumental measurements 1: texture of apple fruit. *Postharvest biology and technology*, *24*(3), 225-239.

Hellyer, J. (2004). Quality testing with instrumental texture analysis in food manufactering. *Middleboro, MA: LPI.[Google Scholar]*.

Jakubczyk, E., Gondek, E., & Tryzno, E. (2017). Application of novel acoustic measurement techniques for texture analysis of co-extruded snacks. *LWT*, *75*, 582-589.

Kadam, S. U., Tiwari, B. K., & O'Donnell, C. P. (2015). Improved thermal processing for food texture modification. *Modifying food texture*, 115-131.

Kim, E. J., Corrigan, V. K., Hedderley, D. I., Motoi, L., Wilson, A. J., & Morgenstern, M. P. (2009). Predicting the sensory texture of cereal snack bars using instrumental measurements. *Journal of Texture Studies*, *40*(4), 457-481.

Kohyama, K. (2020). Food Texture–sensory evaluation and instrumental measurement. *Textural characteristics of world foods*, 1-13.

Lawless, H. T., & Heymann, H. (2010). *Sensory evaluation of food: principles and practices* (Vol. 2). New York: Springer.

Lepetit, J., & Culioli, J. (1994). Mechanical properties of meat. *Meat science*, *36*(1-2), 203-237.

Lillford, P. (2018). Texture and breakdown in the mouth: An industrial research approach. *Journal of texture studies*, *49*(2), 213-218.

Liu, Y. X., Cao, M. J., & Liu, G. M. (2019). Texture analyzers for food quality evaluation. In *Evaluation Technologies for Food Quality* (pp. 441-463). Woodhead Publishing.

Lu, R. (2013). Principles of solid food texture analysis. In *Instrumental assessment of food sensory quality* (pp. 103-128). Woodhead Publishing.

Madieta, E., Symoneaux, R., & Mehinagic, E. (2011). Textural properties of fruit affected by experimental conditions in TPA tests: an RSM approach. *International Journal of Food Science & Technology*, *46*(5), 1044-1052.

Mochizuki, Y. (2001). Texture Profile Analysis. Current Protocols in Food Analytical Chemistry, 00(1).

Nishinari, K., Hayakawa, F., XIA, C. F., Huang, L. O. N. G., MEULLENET, J. F., & SIEFFERMANN, J. M. (2008). Comparative study of texture terms: English, French, Japanese and Chinese. *Journal of texture studies*, *39*(5), 530-568.

Nishinari, K., Kohyama, K., Kumagai, H., Funami, T., & Bourne, M. C. (2013). Parameters of texture profile analysis. *Food Science and Technology Research*, *19*(3), 519-521.

Nishinari, Katsuyoshi (2020). *Textural Characteristics of World Foods || Food Texture – Sensory Evaluation and Instrumental Measurement.*

Otegbayo, B., Aina, J., Abbey, L., SAKYI-DAWSON, E. S. T. H. E. R., Bokanga, M., & Asiedu, R. (2007). Texture profile analysis applied to pounded yam. *Journal of texture studies*, *38*(3), 355-372.

Paula, A. M., & Conti-Silva, A. C. (2014). Texture profile and correlation between sensory and instrumental analyses on extruded snacks. *Journal of food engineering*, *121*, 9-14.

Peleg, M. (2019). The instrumental texture profile analysis revisited. *Journal of Texture Studies*, *50*(5), 362-368.

Pitts, M. J., Davis, D. C., & Cavalieri, R. P. (2008). Three-point bending: an alternative method to measure tensile properties in fruit and vegetables. *Postharvest biology and technology*, *48*(1), 63-69.

Pollen, N. R., Daubert, C. R., Prabhasankar, P., Drake, M. A., & Gumpertz, M. L. (2004). Quantifying fluid food texture. *Journal of texture studies*, *35*(6), 643-657.

Pons, M., & Fiszman, S. M. (1996). Instrumental texture profile analysis with particular reference to gelled systems. *Journal of texture studies*, *27*(6), 597-624.

Ranganna, S. (1986). *Handbook of analysis and quality control for fruit and vegetable products*. Tata McGraw-Hill Education.

Rolle, L., Siret, R., Segade, S. R., Maury, C., Gerbi, V., & Jourjon, F. (2012). Instrumental texture analysis parameters as markers of table-grape and winegrape quality: A review. *American Journal of Enology and Viticulture*, *63*(1), 11-28.

Rosenthal, A. J. (2010). Texture profile analysis–how important are the parameters?. *Journal of texture studies*, *41*(5), 672-684.

Schmilovitch, Z. (2013). *Instrumental Assessment of Food Sensory Quality || Instrumental assessment of the sensory quality of fruits and vegetables. , (), 446–466e.* doi:10.1533/9780857098856.3.446

Singh, V., Guizani, N., Al-Alawi, A., Claereboudt, M., & Rahman, M. S. (2013). Instrumental texture profile analysis (TPA) of date fruits as a function of its physico-chemical properties. *Industrial crops and products*, *50*, 866-873.

Srilakshmi, A. (2020). Texture Profile Analysis of Food and TPA Measurements: A Review Article. *International Research Journal of Engineering and Technology (IRJET)*, *7*, 708-711.

Szczesniak, A. S. (1996). Texture profile analysis-Methodology interpretation clarified (Reprinted from Journal of Food Science, vol 60 pg vii, 1995). *Journal of Texture Studies*, *27*(6), R6-R7.

Szczesniak, A. S. (2002). Texture is a sensory property. *Food quality and preference*, *13*(4), 215-225.

SZCZESNIAK, N. S. (1975). General foods texture profile revisited-ten years perspective. *Journal of texture studies*, *6*(1), 5-17.

Taniwaki, M., Hanada, T., & Sakurai, N. (2006). Device for acoustic measurement of food texture using a piezoelectric sensor. *Food research international*, *39*(10), 1099-1105.

Texture Profile Analysis | Texture Technologies. Retrieved August 27, 2022, from https://texturetechnologies.com/resources/texture-profile-analysis

Trinh, K. T., & Glasgow, S. (2012, September). On the texture profile analysis test. In *Proceedings of the Chemeca* (pp. 23-6).

Tunick, M. H. (2011). Food texture analysis in the 21st century. *Journal of agricultural and food chemistry*, *59*(5), 1477-1480.

Wilkinson, C., Dijksterhuis, G. B., & Minekus, M. (2000). From food structure to texture. *Trends in Food Science & Technology*, *11*(12), 442-450.

Wrolstad, R. E., Acree, T. E., Decker, E. A., Penner, M. H., Reid, D. S., Schwartz, S. J., ... & Sporns, P. (Eds.). (2005). *Handbook of food analytical chemistry, volume 1: Water, proteins, enzymes, lipids, and carbohydrates*. John Wiley & Sons.

Wu, D., Sun, D. W., & He, Y. (2014). Novel non-invasive distribution measurement of texture profile analysis (TPA) in salmon fillet by using visible and near infrared hyperspectral imaging. *Food Chemistry*, *145*, 417-426.

FIGURES AND TABLES

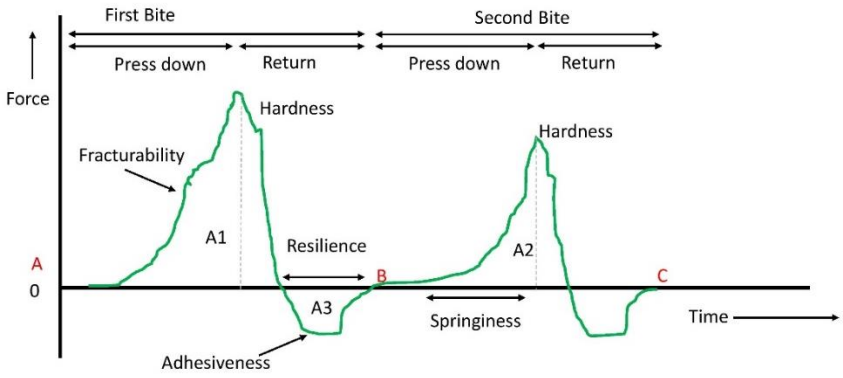

Fig. 1: Typical Texture profile analysis graph

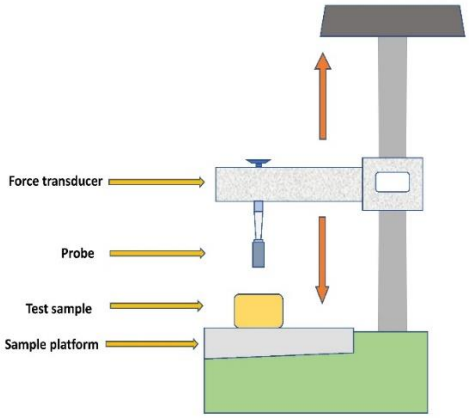

Fig. 2: Schematic diagram of texture profile analyser

Table 1: Probes and its applications (Data is adapted and modified from Liu et al., 2019)

Sr.no	Name of Probe	Test performed	Food Products covered
1	Cylinder probes	Piercing test, Hardness test, elasticity test, resilience test.	Grain and oil products, Bakery products, Meat products, Colloids.
2	Conical probes	Hardness test, rheological test.	For Fluid and semisolid food such as fruit jam, ice cream butter
3	Spherical probes	Elasticity or extensibility test, harness test, viscosity test.	Fruit and cheeses
4	Needle probes	Penetration test	Used to judge the degree of maturity of fruits.
5	Shear probes	Shear test	Meat product's, sausages.
6	Compression probes	Compression test, harness test , resilience test	Fruit and vegetable products, Meat products, hams.

Table 2: Different test performed in TPA with its application in food industry

Sr.no	Name of test	Application in food	References
1	Puncture test	Fruit processing industries, confectionary products, dairy products.	(Hellyer, 2004)
2	Compression test	Solid foods in the fruit and vegetable industry, grains.	(Kaszab et al., n.d.)
3	Shear test	Meat and Meat products	(Lu, 2013)
4	Torsion test	Solid food testing.	(Hamann et al., 2006)
5	Bending test	Muscle food testing	(Lepetit& Culioli, 1994)
6	Three-point bending test	Bakery products and crisp snacks.	(Schmilovitch&Mizrach,2013)
7	Single-edge notched bend test	Biscuit like products.	(Schmilovitch&Mizrach,2013)