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INSTRUMENTAL TEXTURE EVALUATION OF EXTRUDED SNACK FOODS: A REVIEW

EVALUACIÓN INSTRUMENTAL DE TEXTURA EN ALIMENTOS EXTRUIDOS: UNA REVISIÓN

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Abstract

Extrusion cooking technology is the most used technique for the production of snack foods. In such foods, texture is of major importance, with crispness being often a desirable attribute. Due to the high costs involved in sensory analysis, instrumental assessment of end-product texture, by fundamental and empirical techniques, has been a useful tool for food researchers and manufactures as it has been related to sensory evaluation. Among other tests, the texture analysis of expanded snacks has been performed through compression, penetration, acoustic procedures and texture profile analysis. Although this review has focused in instrumental techniques, texture evaluation of extruded snacks is a complex subject, where the combination of techniques involving sensory, instrumental and microstructure analysis would certainly be the best practice. From a practical perspective, empirical methods are suggested as an alternative to fundamental techniques, especially to food scientists and food manufactures interested in predict consumer perception of texture.

Resumen

La tecnologia de cocimiento por extrusión es la técnica mas utilizada para la producción de alimentos extruidos donde la textura es de especial importancia, siendo frecuentemente la crujibilidad el atributo más deseable. Debido a los altos costos del análisis sensorial, la evaluación instrumental de la textura en el producto final, utilizando técnicas fundamentales y empíricas, ha sido una herramienta útil para la investigación en alimentos y para la industria manufacturera ya que se ha correlacionado con la evaluación sensorial. Entre otras pruebas, el análisis de textura de alimentos extruidos se ha llevado a cabo por compresión, penetración, métodos acústicos y análisis de perfil de textura. Aunque esta revisión se enfoca a técnicas instrumentales, la evaluación de textura en alimentos extruidos es un problema complejo, donde la combinación de técnicas incluyendo análisis sensorial, instrumental y de microestructura podría ser la mejor forma de resolverlo. Desde un punto de vista práctico, los métodos empíricos se sugieren como una alternativa a las técnicas fundamentales, especialmente para científicos y productores de alimentos interesados en predecir la percepción de la textura por parte del consumidor.

Keywords: Texture, extrusion, snacks
Palabras clave: Textura, extrusion, alimentos extruidos

INTRODUCTION

Extrusion cooking is an important processing technique in food industry as it is considered an efficient manufacturing process (White, 1994). Food extruders provide thermo-mechanical and mechanical energy (shear) necessary to cause physicochemical changes of raw materials with an intense mixing for dispersion and homogenization of ingredients including conveying, mixing, shearing, heating or cooling, shaping, venting volatiles and moisture, flavor generation, encapsulation, and sterilization (Linko *et al*., 1981; Wiedman and Strobel, 1987). Advantages of this process is that one extruder can operate at relatively low temperatures and produce pasta and baking goods, or at very high temperatures, and then manufacture products with low bulk density, such as snacks and ready to eat cereals (Harper, 1981).

Extruded foods are composed mainly of cereals, starches, and/or vegetable proteins. The major role of these ingredients is to give structure, texture, mouth feel, bulk, and many other characteristics desired for specific finished products (Launay and Lisch, 1983; Jamora *et al*., 2002; Tahnoven *et al*., 1998). Consumer acceptance of extruded foods is mainly due to the convenience, value, attractive appearance and texture found to be particular for these foods, especially when it concerns to snack products (Harper, 1981).

Snack foods comprise a very large variety of items including potato chips, crackers, nuts and extruded snacks, among others (Harper, 1981). Snack food extrusion includes subjecting selected grains to a variety of complex physical processes to yield snacks with varied shapes and textures (White, 1994).

In extruding snack foods, grain and other ingredients are mixed and cooked under pressure, shear at high temperature in a tube, which is also called barrel. The resulting mass is forced through a die, cut into individual pieces and assumes the various shapes that consumers have come to expect in the snack food aisles of markets (Harper, 1981). Novel ingredients, cutting-edge extrusion technology and innovative processing methods are combined to yield new snack products with ever-widening appeal to health-conscious consumers that are seeking different textures and mouth feeling with convenience (Pamies *et al*., 2000).

In order to make products that will be acceptable in a very competitive market, extrusion of snack foods demands the control of many parameters that will directly or indirectly influence the consumer acceptability. Finished product characteristics are partly resulted from specific critical parameters induced in raw materials. The critical parameters that will partly affect the moisture, expansion, solubility, absorption, color, flavor and texture of the final product are (Huber, 2001):

1. Moisture: the actual moisture in the product or extrudate.
2. Thermal energy input: heat from thermal fluids, steam or electricity that is transferred to the heads of the extruders, or direct injection of steam or any other type of liquid additive.
3. Mechanical energy input: heat dissipated into the extrudate caused by the shearing and pumping action in the extruder barrel.
4. Retention time: total time the product is in any specific region of the extrusion process.

In addition, several extrusion processing conditions are accounted for the quality of finished products. The control of feed rate, screw speed, barrel temperature and barrel pressure, together with the above mentioned critical parameters, will determine the crispness, hardness and various other characteristics that will influence the success of the product (Harper, 1981). The success or failure of a new extruded snack food product is directly related to sensory attributes, where texture plays a major role. In such foods, where expansion is desired and puffed products are expected, texture is of major importance, with crispness being one of the most important attribute (Pamies *et al*., 2000).

Several researchers agree that crispness should result from the structural properties of a food (Bouvier *et al.*, 1997; Mohamed *et al.*, 1982; Stanley and Tung, 1976). According to Heidenreich *et al*. (2004), crispness is perceived through a combination of tactile, kinesthetic, visual and auditory sensations and represents the key texture attributes of dry snack products. Moreover, crispness is related with rapid drop of force during mastication process, attribute that is based on fracture propagation in brittle materials (Vincent, 1998). When force is applied to brittle snacks, rupture of the cellular structure occurs, generating a typical sound that contributes to the crispness sensation (Vickers and Bourne, 1976). Materials considered to be crisp usually generate irregular force–deformation curves.

Thus, quality evaluation of extruded snack foods seems to be correlated with sensory, instrumental and microstructure characteristics, which all together will account for a product with high acceptability. In sensory analysis of extruded snack foods, highly trained panels or laboratory panels are usually the most applied techniques. Parameters regarding crispness, crackliness and hardness are the most studied, often indicating a good relationship between human perception and instrumental analysis of texture (Liu *et al*., 2000; Pamies *et al*., 2000; Veronica *et al*., 2006).

INSTRUMENTAL TECHNIQUES FOR TEXTURE EVALUATION OF EXTRUDED SNACK FOODS

Instrumental analysis of texture in foods provides fast and relatively inexpensive indications on product characteristics and consumer acceptance. In the scientific literature attempts using different methods of approach have been reported, providing varied perspectives on texture attributes of extruded snacks (Table 1). Katz and Labuza (1981) evaluated the crispness and shear resistance of several products, including extruded snacks, by a sensory test and by the Instron machine. Different types of cutting devices were used and they found that the initial slope of the force-deformation curve correlated with crispness, stating that the mechanical shear force can be used as indicator of crispness in expanded cereals. However, this statement would be valid only when the water activity of the product is lower than the critical value, as the results from the sensory analysis indicated that beyond that point a loss of acceptability would be found and the relationship between sensory and instrumental analysis would no longer be reliable.

In 1986, Stanley found a good negative relationship between the shear force needed to fracture and the expansion of puffed cereal. Using a universal texture analyzer with a Warner-Bratzler device, the author associated the force deformation curve to the microstructure. This observation was made on the basis that the number of peaks before fracture was directly related to the porosity of the extrudate, which was proposed to be useful for the determination of crispness and

Table 1. Summary of instrumental techniques used to evaluate texture/microstructure of extruded snack foods.

Tabla 1. Resumen de técnicas instrumentales usadas para evaluar la textura o microestructura de alimentos extruidos.

Parameters observed	Instrument/technique	Authors
Empirical		
Crispness	Instron machine	Katz and Labuza, 1981
Crispness and brittleness	Universal texture analyzer	Stanley, 1986
Crispness/crunchiness	Various - Review	Vickers, 1985 Szczesniak, 1988 Vincent, 1998 Duizer, 2001
Hardness	Instron machine	Grenus *et al*., 1993
Breaking strength index	TA-XT2	Onwulata *et al*., 2001 Onwulata and Konstance, 2006
Brittleness, breaking strength and hardness	TA-XT2i	Veronica *et al*., 2006
Hardness and total energy required to puncture	TA-XT2	Ding *et al*., 2006
Fracturability, cohesiveness, adhesiveness, hardness and chewiness	TA-XT2	Bourne, 1975 Halek *et al*., 1989 Liu *et al*., 2000
Fundamental		
Shear stress	Instron machine	Chávez-Jáuregui *et al*., 2000
Shear force	TAHDi	Mazunder *et al*., 2007
Apparent compressive strain		Ravi *et al*., 2007
True compressive strain		
Apparent compressive stress		
True compressive stress		
Young's modulus		
Microstructure		
Protein network	Scanning electron microscopy	Chaunier *et al*., 2006
Starch structure		Mazunder *et al*., 2007
Pore size	X-ray tomography Confocal scanning light microscopy Differential scanning calorimetry	Onwulata and Konstance, 2006

brittleness. Likewise, Grenus *et al*. (1993) studied the physical properties of extruded rice flour mixed with rice bran using the Instron machine and the Warner-Bratzler cutting device. The authors calculated the ratio between the shear force and cross-sectional area of the product to verify the hardness of the extrudates.

Onwulata *et al*. (2001) studied the breaking strength index (BSI) of extruded corn, potato or rice snacks incorporated with whey. This parameter was determined through a texture analyzer TA-XT2 (Stable Micro Systems, Surrey, England) and calculated using: BSI = Peak breaking force (N)/extrudate diameter (mm). The authors observed that as the whey concentration increased (either sweet whey solids or whey protein concentrate) the quality parameters for expansion and breaking force decreased significantly. Recently, using the same method, Onwulata and Konstance (2006) studied the effect of particle size on extruded corn meal and whey protein concentrate. In this study the authors found that the blend of whey protein concentrate and corn meal with similar particle size distribution of both ingredients showed extrudates characteristics similar to those made from corn meal alone (control). Controlling moisture content, it was demonstrated the beneficial effect of homogeneity in particle size on quality attributes such as expansion ratio, porosity and breaking strength.

The texture profile analysis (TPA) of puffed extruded snacks is also an alternative to sensory analysis as it indicates to be well correlated with the latter. To measure the quality of extruded puffed snacks from maize/soybean mixture, Veronica *et al*. (2006) conducted a TPA using a TA-XT2i texture press (Texture Technologies Corporation, Scarsdale, NY). In this experiment, pieces of uniform length and diameter were taken from each sample, which were placed on the loading cell and compressed under specific conditions. The charges in the force required to break the sample during compression were recorded in the form of peak and the texture was expressed as brittleness (force [N] required to cause the first peak), breaking strength (maximum force [N] required to break the sample) and hardness (peak force [N] of the first compression required for sample's breakage). A sensory analysis was also performed in this study, and the findings suggested a good relationship between the results from the instrumental and sensory procedures used. An increase in breaking strength and hardness and a decrease in brittleness were inversely correlated with consumer perception and judgment of «just about right» degrees of puffiness and crispness. It was also inversely associated with overall acceptability, as characteristics such as color, flavor, and taste were negatively affected by the incorporation of soybean in the maize flour. Regarding the instrumental data interpretation, as the puffed extrudates were expected to be crisp, brittleness was calculated as the force required to cause the first peak in the force-deformation plot. In crack materials, such as crackers, the first peak would probably indicate fracture, what does not happen in the case of puffed snacks due to the presence of air pockets placed in between a solid matrix. The expansion caused by the extrusion at high pressure and temperatures may lead to crisp end-products that present several peaks before fracture (highest peak followed by a sudden drop) in a force-deformation curve from a compression test. The works of Vincent (1998) and Duizer (2001) explain and illustrate differences in evaluation of foods with varied physical profiles.

Following the interpretation method reported by Bourne (1975), Liu *et al*. (2000) performed a TPA of extruded oat-corn puffs and found a high correlation with human sensory perception of specific textural attributes. Instrumentally, texture parameters such as fracturability, cohesiveness, adhesiveness, hardness and chewness were calculated based on a compression test. The procedure described by Halek *et al*. (1989) was used to the instrumental settings, which were applied on a TA-XT2 texture analyzer. Briefly, the sample was compressed twice at 70 % of its original height and the force deformation curve was recorded. It is important to mention that when empirical tests are being conducted, the sample size has to be well defined and uniform among replicates, otherwise the reproducibility of outcomes is compromised. In this study the extrudates were cut to 10 mm long cylindrical specimens with a sharp blade and each sample had six replicates. When correlating sensory to instrumental data, the group observed a high correlation between hardness from the machine to the hardness evaluated by the human bite. Although the results from such investigation are interesting, the method of interpretation suggested by Bourne (1975) may not be the best applied to extruded snacks, as these foods are not meant to present any degree of elasticity (recovery after compression).

The effect of extrusion conditions on the functional and physical properties of wheat-based expanded snacks has been investigated (Ding *et al*., 2006). In this study, the texture characteristics of extrudates were measured using a stable micro system TA-XT2 texture analyzer (Surrey, UK). Samples were punctured by a 2 mm cylinder probe to a determined distance which corresponded to approximately 40–60 % of the diameter of the extrudates. The characteristics evaluated were related to the peak force, which represented the resistance of extrudate to initial penetration and is believed to be the hardness of the extrudate, and to the area under the curve, which was considered the energy required for the given displacement. This technique was found useful in particular for the study of feed moisture on the total energy required to puncture the extrudate. By this method, the authors observed the indication of a brittle texture resulted from a sharp decrease in the energy required to puncture the wheat extrudate, consequence of increased feed moisture and hardness.

Mazunder *et al*. (2007) investigated the textural attributes for a model snack food at different moisture contents and used uniaxial compression to evaluate texture. Employing fundamental techniques through a texture measuring instrument (Model TAHD$_i$, Stable Microsystems, Surrey, UK), the samples were compressed between two parallel plates of specific dimensions. From the force–deformation curves, parameters such as maximum force, energy for compression, number of major peaks, and initial slope of the linear portion of curve were determined. The maximum force was taken as the peak force offered by the sample during compression or at failure, whichever was higher. Firmness was primarily the deformation modulus of the material under test and was obtained from the slope of the initial linear portion of the force–deformation curve. Engineering stress and strain and true stress and strain were determined to calculate Young's modulus. Briefly describing, the engineering or apparent compressive strain ($å_E$) was calculated by using equation 1 as:

$$\varepsilon_E = \frac{\Delta h}{h_0} \qquad (1)$$

where h_0 is the initial height of the sample and Ä*h* is the change in height due to compression. The true, natural, or Hencky's compressive strain ($å_T$) was given by equation 2 as:

$$\varepsilon_T = \ln\left(\frac{h_0}{h_0 - \Delta h(t)}\right) \qquad (2)$$

The engineering or apparent compressive stress ($ó_E$) was determined from the force–time plot and by knowing the cross-sectional area of the sample prior to compression, as observed in equation 3:

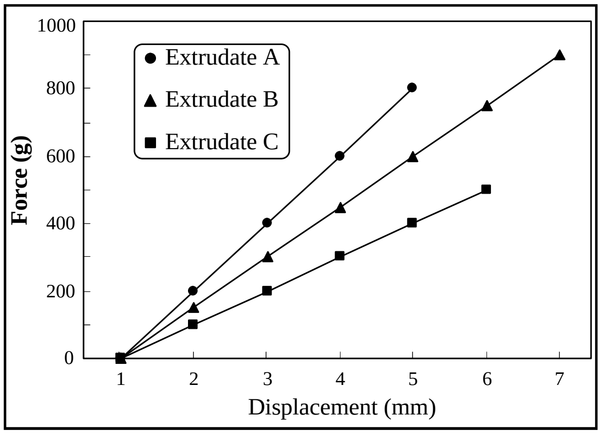

Figure 1. Schematic force-displacement linear representation of discriminatory test using slope magnitude and degree of force necessary to break the sample as indication of crispness and brittleness of extrudates A, B, and C through a compression test. In this sense, the extrudate A would be the most crisp (highest slope) and the second most brittle (maximum force applied until rupture higher than extrudate C and lower than extrudate B). Extrudate B would be the most brittle and extrudate C would be likely to be recognized by a sensory panel as the least crisp and brittle.

Figura 1. Representación esquemática del comportamiento fuerza-desplazamiento lineal de la prueba discriminatoria usando la magnitud de la pendiente y el grado de fuerza necesaria para romper la muestra como indicador de crujibilidad y fragilidad de alimentos extruidos A, B y C a través de una prueba de compresión. En este sentido, el extruido A sería el mas crujiente (la pendiente más alta) y el segundo más frágil (máxima fuerza aplicada para su ruptura, más alto que para el extruido C y más bajo que el extruido B). El extruido B sería el más frágil y el extruido C probablemente sería reconocido por un panel sensorial como el menos crujiente y frágil.

$$s_E = \frac{F(t)}{A_0} \quad (3)$$

In addition, the true stress was calculated by equation 4:

$$s_T = \frac{F(t)}{A(t)} = \frac{F(t)(h_0 - \Delta h(t))}{A_0} \quad (4)$$

Young's modulus, which is equal to the ratio of true stress and strain, was expressed as:

$$g = \frac{s_T}{e_T} \quad (5)$$

Similar fundamental approaches have been reported in the literature (Chávez-Jáuregui *et al*. 2000; Ravi *et al*., 2007). Furthermore, the relationship that acoustic sensations have with the perception of texture has been studied for crisp, crunchy and crackly products (Duizer, 2001). This has involved evaluating the contribution of chewing sounds to the perception of these textures or recording noises produced during mastication and evaluating various acoustic parameters from the resulting amplitude–time curves. Briefly, it has been reported that both crisp and crunchy foods exhibit a crunchy sound (Szczesniak, 1988). The difference between the two sensations is that crisp foods demonstrate a higher pitched and louder sound than the ones originated from the bite of crunchy foods such as toasted almonds (Vickers, 1985). The description and interpretation of various methods of acoustic analysis of crispness and crunchiness is well described by Duzier (2001).

Recently, research has been conducted in order to correlate the results of some of the described methods with microstructure of extruded snacks (Chaunier *et al*., 2007; Mazunder *et al*., 2007; Onwulata and Konstance, 2006). This approach would be helpful in explaining the molecular basis of instrumental data and manipulating the conditions to specific desirable characteristics. Techniques such as scanning electron microscopy (SEM), X-ray tomography, confocal scanning light microscopy (CSLM) and differential scanning calorimetry (DSC) provide important information that seems to be well correlated to findings originated in instrumental analysis (Chaunier *et al*., 2006; Mazunder *et al*., 2007; Onwulata and Konstance, 2006).

CONCLUSION

Fundamental techniques have been applied to evaluate material properties of extruded snacks (Chávez-Jáuregui *et al*., 2000; Mazunder *et al*., 2007; Ravi *et al*., 2007). These methods indicate to be valid approaches to study engineering properties of extruded snacks. However, from a practical perspective, empirical methods seem to correlate better to sensory analysis, besides being easier to interpret.

Empirical techniques applied to expanded snacks, as indicated, would be an easy and straightforward approach to discriminatory tests and prediction of consumer acceptance. Characteristics such as brittleness, breaking strength and hardness could be evaluated, being directly correlated to human perception. As the quantification of crispness and brittleness has been related to the slope magnitude and the degree of force required to break the sample (Katz and Labuza, 1981; www.texturetechnologies.com/brittle.htm), it is suggested that discriminatory tests could be performed by compression techniques that generate graphs of simple interpretation. Figure 1 schematically represents a discriminatory test using slope magnitude and degree of force necessary to break the sample as indication of crispness and brittleness of 3 different extrudates. In Figure 1 minor peaks are not presented, however in a practical experiment irregular curves would result. Nonetheless, the slope and maximum force required to break the sample herein showed could be easily identified in experimental procedures. Basically, this representation is analyzed in such a manner that the higher the slope the higher the degree of crispness, whereas brittleness is inversely correlated to the maximum force required to break the sample (the lower the force the higher the brittleness) (Katz and Labuza, 1981; Vickers and Christensen, 1980; www.texturetechnologies.com/brittle.htm).

Regarding the material fundamental properties, undoubtly the fundamental methods presented would be the most appropriate practices to achieve it. If the food researcher or engineer is interested in determining parameters such as compressive stress, Hencky's compressive strain or Young's modulus, uniaxial compression and the stress-strain curves resulted would provide these and much more information. Furthermore, by this method of approach, the fundamental properties of the material could be easily compared with similar investigations reported in the literature. However, the experimenter must be well familiarized with the equations and procedures involved in this type of texture analysis, as the degree of complexity in dealing and interpreting the outcomes is higher than the empirical procedures.

In addition, the food scientist interested in investigate food texture can not forget about sensory analysis, microstructure and other methods not discussed here. For example, combining the analysis of acoustic recordings with mechanical testing results appears to be an interesting technique for predicting crispness and crunchiness of snack foods (Duizier, 2001). Also, the importance of human sensory analysis can not be denied, and efforts in finding the «perfect» method that reflects human perception must be continuous, as there are still many issues to be solved.

Thus, it is observed that texture evaluation of extruded snacks is a complex and multidisciplinary subject, where the combination of techniques is certainly the best practice. Nonetheless, empirical methods are suggested as a practical alternative to fundamental techniques to food scientists and food manufactures. In this context, if the main interest is to relate instrumental analysis to human sensory perception regardless of the material fundamental properties, empirical techniques are recommended as convenient and valuable approaches.

REFERENCES

Bourne, M. C. 1975. Texture properties and evaluation of fabricated foods, pp 127-158. In G. E. Inglett (ed.), Fabricated foods. Van Nostrand Reinhold/AVI, New York.

Bouvier, J. M.; Bonneville, R.; Goullieux, A. 1997. Instrumental methods for the measurement of extrudate crispness. *Agro-Food-Industry Hi-Techology* **8**, 16-19.

Chaunier, L.; Valle, G. D.; Lourdin, D. 2007. Relationships between texture, mechanical properties and structure of cornflakes. *Food Research International* **40**, 493-503.

Chávez-Jáuregui, R. N.; Silva, M. E. M. P.; Arêas, J. A. G. 2000. Extrusion cooking process for Amaranth (*Amaranthus caudatus* L.). *Journal of Food Science* **65**, 1009-1015.

Ding, Q.; Ainsworth, P.; Plukett A.; Tucker, G.; Marson, H. 2006. The effect of extrusion conditions on the functional and physical properties of wheat-based expanded snacks. *Journal of Food Engineering* **73**, 142-148.

Duizer, S. 2001. A review of acoustic research for studying the sensory perception of crisp, crunchy and crackly textures. *Trends in Food Science & Technology* **12**, 17–24.

Grenus, K. M.; Hsieh, F.; Huff, E. H. 1993. Extrusion and extrudate properties of rice flour. *Journal of Food Engineering* **18**, 229-245.

Halek, G. W.; Paik, S. W.; Chang, K. L. B. 1989. The effect of moisture content on mechanical properties and texture profile parameters of corn meal extrudates. *Journal of Texture Studies* **20**, 43-55.

Harper, J. M. 1981. Extrusion of Foods, Vol. 1, CRC Press, Inc. Boca Raton, FL.

Heidenreich, S.; Jaros, D.; Rohm, R.; Ziems, A. 2004. Relationship between water activity and crispness of extruded rice crisps. *Journal of Texture Studies* **35**, 621–633.

Huber, G. 2001. Snack Foods from Cooking Extruders, pp 1-33. In R. W. Lucas; L. W. Rooney (ed.), Snacks Food Processing, CRC Press, Inc., Boca Raton, FL.

Jamora, J. J.; Rhee, K. S.; Rhee, K. C. 2002. Chemical and sensory properties of expanded extrudates from pork meat-defatted soy flour blends with onion, carrot and oat. *Journal of Food Science and Nutrition* **6**, 158–162.

Katz, E. E.; Labuza, T. P. 1981. Effect of water activity on the sensory crispness and mechanical deformation of snack food products. *Journal of Food Science* **46**, 403-409.

Launay, B.; Lisch, J. M. 1983. Twin-screw extrusion cooking of starches: flow behaviour of starch pastes, expansion and mechanical properties of extrudates. *Journal of Food Engineering* **2,** 259–280.

Linko, P.; Colonna, P.; Mercier, C. 1981. High temperature, short time extrusion-cooking. *Advances in Cereal Science and Technology* **4**, 145–235.

Liu, Y.; Hsieh, F.; Heymann, H.; Huff, H. E. 2000. Effect of process conditions on the physical and sensory properties of extruded oat-corn puff. *Journal of Food Science* **65**, 1253-1259.

Mazunder, P.; Roopa, B. S.; Bhattacharya, S. 2007. Textural attributes of a model snack food at different moisture contents. *Journal of Food Engineering* **79**, 511–516.

Mohammed, A. A. A.; Jowitt, R.; Brennan, J. G. 1982. Instrumental and sensory evaluations of crispness: 1 – in friable foods. *Journal of Food Engineering* **1**, 55-75.

Onwulata, C. I.; Konstance, R. P. 2006. Extruded corn meal and whey protein concentrate: effect of particle size. *Journal of Food Processing and Preservation* **30**, 475-487.

Onwulata, C. I.; Konstance, R. P.; Smith, P. W.; Holsinger, V. H. 2001. Co-extrusion of dietary fiber and milk proteins in expanded corn products. *Lebensmittel Untersuchung Forschung* **34**, 424-429.

Pamies, B. V.; Roudaut, G.; Dacremont, C.; Meste, M. L.; Mitchell, J. R. 2000. Understanding the texture of low moisture cereal products: mechanical and sensory measurements of crispness. *Journal of the Science of Food and Agriculture* **80**, 1679-1685.

Ravi, R.; Roopa, B. S.; Bhattacharya, S. 2007. Texture evaluation by uniaxial compression of some snack foods. *Journal of Texture Studies* **38**, 135-152.

Stanley, D. W. 1986. Chemical and structural determinants of texture of fabricated foods. *Food Technology* **12**, 65-76.

Stanley, D. W.; Tung, M. A. 1976. Microstructure of food and its relationship to texture. In J. M. DeMan; P. W. Voisey; V. F. Rasper; D. W. Stanley (ed.), Rheology and Texture in Food Quality, AVI Publishing Co., Inc., Westport, CT.

Szczesniak, A. S. 1988. The meaning of textural characteristics – crispness. *Journal of Textural Studies* **19**, 51-59.

Tahnoven, R.; Hietanen, A.; Sankelo, T.; Kortaniemi, V. M.; Laakso, P.; Kallio, H. 1998. Snack foods. *Lebensmittel Untersuchung Forschung* **206,** 360–363.

Veronica, A. O.; Olusola, O. O.; Adebowale, E. A. 2006. Qualities of extruded puffed snacks from maize/ soybean mixture. *Journal of Food Processing Engineering* **29**, 149-161.

Vickers, Z. M.; Bourne, M. C. 1976. A psychoacoustical theory of crispness. *Journal of Food Science* **41**, 1158–1164.

Vickers, Z. M.; Christensen, C. M. 1980. Relationships between sensory crispness and other sensory and instrumental parameters. *Journal of Textural Studies* **11**, 291-308.

Vickers, Z. M. 1985. The relationships of pitch, loudness and eating technique to the judgments of the crispness and crunchiness of food sounds. *Journal of Textural Studies* **16**, 85-95.

Vincent, J. F. V. 1998. The quantification of crispness. *Journal of Science of Food and Agriculture* **78**, 162–168.

White, G. 1994. Defining the true meaning of snacks. *Food Technology International Europe* **2**, 115-117.

Wiedman, W.; Strobel, E. 1987. Processing and economic advantages of extrusion cooking in comparison with conventional processing in the food industry, pp 132-169. In C. O'Connor (ed.), Extrusion Technology for the Food Industry. Elsevier Applied science, New York.