Effect of deep-fat frying on sensory and textural attributes of pellet snacks

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Abstract In this paper, the effects of several frying parameters on the quality of indirect expanded snacks were studied. Pellets, in two colors of yellow and green, were deep-fat fried at 150, 170, and 190 °C for 0.5, 1.5, 2.5, 3.5, and 4.5 min; then, subjected to uniaxial compression test and sensory analysis. The results showed that hardness, fracture force and apparent modulus of elasticity reduced with increase in frying time and temperature due to puffing samples and decrease in crust thickness. In contrast, higher frying temperature improved the crispness of samples. Panelists preferred the flavor, color, and total acceptance of yellow samples to the green ones. Moreover, principal component analysis (PCA) of instrumental and sensory data provided important information for the correlation of objective and sensory properties.

Keywords Compression test · Extruded snack · Principal component analysis · Sensory evaluation

Introduction

Snack foods are an integral part of the diet and have been commercially exploited on a wide scale (Senthil et al. 2002). The term ‘snack’ or ‘snack food’ is difficult to define or categorize. Webster’s New Ninth Collegiate Dictionary defines it as “a light meal, food eaten between regular meals, food suitable for snacking” (Lucas 2001).

Snack foods extrusion consists of subjecting selected grains to a variety of complex physical processes to yield

snacks with various shapes and textures (White 1994). Direct expanded snacks, coextruded snacks, and indirect expanded ones are three types of extruded snacks. Indirect expanded products, that also referred to as ‘third-generation snacks’ and ‘half-products’, are not expanded directly through the die. The additional processes which contribute to the appearance or texture include frying or hot-air puffing to remove moisture and achieve the final texture. Pellets and fabricated chips are two sub-categories of these products (Bawa and Sidhu 2003).

Deep-fat frying is the most unit operation in food preparation, as evidenced by the worldwide annual production of more than 20 million tons of frying oil (Dana and Saguy 2006). During this process, the fat acts as heating medium and it is immiscible with water. Due to high temperature, water within the food material gets heated and pumped out into the surrounding oil in the form of steam (Math et al. 2004). Frying has also been reported as the most common method for expanding the pellets; because it is less expensive and works well (Bawa and Sidhu 2003).

Texture and flavor are of the most important attributes of fried foods and are always issues in the manufacturing of fried food products. Before frying, characteristics of the food, such as water content, size, types and amount of protein and starch, composition of coating materials and additives are important factors which influence the desired texture of end product. Processing variables, such as frying time and temperature, cooling condition, moisture control, etc., should also be considered (Shieh et al. 2004).

Several sensory terms, such as crispy, crunchy and crumbly, are often used to describe the specific textural characteristics of snack foods. Complexity of the multi-component nature of the food system has developed different kinds of textural measuring systems and instruments that operate under various conditions of stresses, including compression,

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shearing, tensile, bending and snapping, compression–extrusion, etc. (Bourne 2002). Among these methods, compression is the most common technique because of its simplicity of operation that partially simulates the action of jaws inside the mouth (Ravi et al. 2007).

Literature review shows that there have been many researches into the textural quality of different kinds of snacks (Katz and Labuza 1981; Halek et al. 1989; Liu et al. 2000; Pamies et al. 2000; Rampersad et al. 2003; Veronica et al. 2006; Ainsworth et al. 2007; Ravi et al. 2007; Nath and Chattopadhyay 2008; Greve et al. 2010; Lazou and Krokida 2010). However, to our knowledge, there is no or little study available concerning the effects of different combinations of time and temperature of deep-fat frying on sensory and textural properties of pellet snacks. Hence, the objectives of this paper were (1) to determine the textural attributes during uniaxial compression of snacks fried at various times and temperatures, (2) to assess effects of frying conditions on sensory attributes (3) to reduce large number of sensory attributes to two independent principal component, and (4) to find relations between textural and sensory attributes by using principal component analysis.

Materials and methods

Materials

Pellet snacks (Alvand processing Co. Behzad Persian food industrial group, Tehran, Iran), in two colors of yellow and green, and vegetable frying oil (Bahar, Behshahr Industrial Co., Behshahr, Iran) were purchased from local market. Snack products contained wheat flour, emulsifier, salt and food-grade colors. Average length, width, and thickness of snacks were 26.47, 7.75, and 7.52 mm, respectively. A sample of yellow snack, before and after of frying at 150, 170, or 190 °C for 1.5 min, is presented in Fig. 1.

Fig. 1 Change in texture and size of yellow pellets during deep-fat frying (**a**: un-fried sample; **b**: fried at 150 °C for 1.5 min; **c**: fried at 170 °C for 1.5 min; **d**: fried at 190 °C for 1.5 min)

Methods

Frying

The frying process was accomplished in a thermostatically temperature controlled fryer (Crown Co., XB5356 model, China) containing 1.5 L frying oil. The fresh oil was pre-heated to frying temperature in 30 min before the snacks were fried in it. Samples placed in the frying basket were immersed into the oil when the desired temperature (150, 170, or 190 °C) was achieved. After the frying time (0.5, 1.5, 2.5, 3.5, or 4.5 min), the samples were immediately removed from oil, were blotted with the tissue paper to remove excess oil on the surface, and allowed to cool at room temperature before analyses.

Texture measurement

Instrumental texture measurements were obtained at room temperature using a Texture Analyzer (CNS Farnell Com, U.K.) immediately up to 1 h after deep-fat frying and cooling. Uniaxial compression test, by a 35 mm diameter plastic cylinder, was made on the snacks which were mounted over a platform. Samples were compressed to 30 % strain at a constant speed of 25 mm/min (Halek et al. 1989). The texture of snacks was expressed as fracture force (highest peak followed by a sudden drop [g]), hardness (peak compression force [g] at target deformation), apparent modulus of elasticity or initial target modulus (sample rigidity that is the linear part of the force-deformation curve [g/s]), adhesiveness (negative force area during withdrawal [g.s]), and compressive energy (area under the curve for the compression that is the work [g.s] required to attain deformation indicative of internal strength of bonds within product) (Halek et al. 1989; Ahmed et al. 2005; Anton and Luciano 2007; Kim et al. 2009).

Sensory evaluation

Snack samples were organoleptically examined by six trained panelists (three female, three male, ages 23 to 32 year). Sensory attributes were evaluated by panelists according to Liu et al. 2000; Bourne 2002. Evaluation was done under normal white fluorescent lighting at temperature of 22 ± 1 °C. Rating of samples was carried out using a nine point scale where 1 = non-existent – imperceptible characteristic, and 9 = too intense. Throughout panel sessions, panelists were instructed to rinse their mouths with water before testing each sample.

Statistical analysis

A completely randomized factorial design was used to evaluate the results and analysis of variance (ANOVA) was carried out to compare the mean values. Frying time and temperature, color of snack and interaction among them were considered as process variables. All significant differences are reported at $P=0.05$ level. Both sensory and textural parameters were also subjected to principal component analysis to explore the underlying relationships between them. Minitab statistical software (Minitab Release 14, Minitab Inc., USA) was used for all statistical analyses in the present research. Sensory and texture measurements were performed in at least four and six replications, respectively.

Results and discussion

Results of textural and sensory attributes of pellet snacks are presented in Tables 1, 2 and 3. As shown in Fig. 1, frying at suitable time and temperature caused samples to puff. Shorter frying times (e.g. 0.5 or 1.5 min) at 150 °C were not enough for expanding the pellets, however, longer times or higher temperatures could produce desirable texture. Rapid heating in frying process causes the water in the product to turn into steam in an explosive manner which puffs the pellet (Bawa and Sidhu 2003).

Texture measurement

Tables 1 and 2 show that textural attributes of fracture force, hardness, apparent modulus, and compressive energy reduced with increase in frying time and temperature that is due to puffing samples and decrease in crust thickness. Moreover, values of fracture force, apparent modulus and adhesiveness were higher for yellow snacks than the green ones.

Fracture force

Significant decrease ($P<0.05$) in fracture force of samples was observed with increase in frying time, temperature and interaction between them (Tables 1 and 2). This finding is similar to results of Stanely (1986) who established a good negative relationship between the fracture force and the expansion of puffed cereal. Moreover, 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 brittleness. A low fracture force is desirable for the consumption of a puffed cereal or a snack (Roopa et al. 2009). ANOVA showed that color of pellets did not have statistically important influence on fracture force ($P>0.05$).

Hardness

Hardness of samples varied from 450.70 to 1686.70 g in yellow snacks and 460.40 to 1458.70 g in the green ones (Tables 1 and 2). Among studied factors (time and temperature of frying, color of snacks and interactions between them), influence of temperature, frying time, and temperature $\times$ frying time was statistically important ($P<0.05$).

Apparent modulus of elasticity

The initial slope on a force-deformation curve is referred to as the ‘elastic modulus’ or the ‘modulus of deformability’. This modulus, measured before any degree of structural failure has taken place, is related to the firmness of the sample (Shieh et al. 2004).

Frying time and temperature and interaction between them had significant impact ($P<0.05$) on apparent modulus of elasticity of samples that ranged from 84.23 to 2015.11 g/s in yellow snacks and 57.88 to 1274.41 g/s in the green ones (Tables 1 and 2). Temperature of 150 °C could not expand the samples sufficiently (Fig. 1), especially in 0.5 min frying. Then, samples treated with these conditions had not desired puffed structure and were significantly rigid.

Adhesiveness

Adhesiveness refers to amount of work needed to overcome the attractive forces between the surface of the food product and the surface of the material with which it comes in contact (Szczeniak 1975). This is more of a surface characteristic and depends on a combined effect of adhesive and cohesive forces, and others including viscosity and viscoelastic as well (Adhikari et al. 2001).

Results of instrumental measurement showed that snacks were very low adhesive (Tables 1 and 2) that could be associated with low water content of this kind of products.

Table 1 Textural attributes of yellow pellets as affected by time and temperature of deep-fat frying

Texture parameter	Temperature (°C)	Yellow pellets- frying time (min)				
		0.5	1.5	2.5	3.5	4.5
Fracture force (g)	150	1271.8±376.19	344.5±132.41	372.3±114.53	265.6±89.99	322.5±124.39
	170	266.3±89.57	75.3±48.22	99.8±23.28	81.3±21.34	53.4±27.78
	190	78.6±49.28	36.8±21.01	28.0±12.00	48.0±14.08	25.3±9.00
Hardness (g)	150	1686.7±301.23	1140.0±327.99	902.5±420.33	852.6±422.78	945.0±388.01
	170	693.8±231.01	647.3±390.21	693.1±421.62	589.1±310.21	662.0±330.31
	190	542.3±310.24	500.8±269.12	450.7±318.55	471.0±321.56	506.2±211.13
Apparent modulus of elasticity (g/s)	150	2015.1±220.87	470.3±101.01	466.3±146.23	585.7±201.02	446.8±198.87
	170	252.3±110.21	109.8±34.15	102.0±39.95	84.2±33.26	90.8±40.02
	190	100.5±52.87	106.9±41.23	93.1±43.56	124.8±50.13	104.0±43.65
Adhesiveness (g.s)	150	0.75±0.200	0.02±0.005	0.03±0.008	0.11±0.012	0.08±0.021
	170	0.02±0.011	0.00±0.001	0.00±0.003	0.01±0.006	0.00±0.000
	190	0.07±0.031	0.00±0.002	0.27±0.010	0.01±0.005	0.01±0.007
Compressive energy (g.s)	150	3485.1±665.20	2746.0±432.11	3002.1±521.08	2449.2±432.02	2872.4±399.65
	170	924.0±256.13	2433.7±566.87	1635.0±454.96	1729.6±600.13	1350.1±402.35
	190	2277.5±353.02	2036.4±323.99	1223.2±300.67	1577.3±377.20	1984.8±536.07

Number of replications ($n=4$)

The interaction of water with solids has been mentioned as the prime cause of adhesiveness in low-moisture foods (Adhikari et al. 2001). The lowest adhesiveness was found in yellow pellets fried at 170 °C for 2.5 min or 190 °C for 1.5 min; while, yellow samples fried at 150 °C for 0.5 min had the highest adhesiveness. Only simultaneous effect of frying time $\times$ temperature on this attribute was significant ($P<0.05$).

Compressive energy

Compressive energy values varied from 923.99 to 3485.12 g.s, with the snacks fried at 170° for 0.5 min having the least amount, and the pellets fried at 150° for 0.5 min having the highest value (Tables 1 and 2). Yellow samples gained the both highest and lowest values. Effects of frying temperature, frying

Table 2 Textural attributes of green pellets as affected by time and temperature of deep-fat frying

Texture parameter	Temperature (°C)	Green pellets- frying time (min)				
		0.5	1.5	2.5	3.5	4.5
Fracture force (g)	150	503.7±241.38	369.8±152.28	185.2±65.29	210.0±79.00	163.9±87.26
	170	94.1±31.23	71.1±20.02	95.8±40.29	233.8±108.83	68.6±41.31
	190	47.7±12.11	54.4±14.91	55.5±29.01	68.2±31.15	45.2±19.00
Hardness (g)	150	1458.7±482.22	1157.0±489.01	1243.8±501.13	1083.9±331.12	1069.2±421.01
	170	673.5±251.36	697.2±321.25	698.2±333.31	574.0±311.59	606.3±206.07
	190	482.4±200.11	469.0±215.09	478.0±231.22	460.4±221.22	556.8±252.08
Apparent modulus of elasticity (g/s)	150	1274.4±321.02	409.9±102.31	765.3±187.45	648.5±123.65	404.8±211.25
	170	127.7±39.45	99.7±42.35	118.8±46.37	76.7±19.00	112.1±23.99
	190	100.8±41.37	57.9±18.72	107.4±39.81	85.4±23.47	88.6±28.01
Adhesiveness (g.s)	150	0.39±0.124	0.08±0.013	0.03±0.005	0.01±0.006	0.06±0.015
	170	0.03±0.009	0.04±0.007	0.02±0.009	0.08±0.019	0.04±0.010
	190	0.02±0.010	0.08±0.020	0.02±0.007	0.01±0.004	0.02±0.008
Compressive energy (g.s)	150	2605.5±876.76	2442.9±658.21	2804.8±532.09	2716.4±652.02	2221.3±600.07
	170	1269.3±467.01	2730.2±375.23	2401.1±405.05	2208.0±589.21	2241.8±490.51
	190	1627.4±429.00	1822.9±490.32	1607.7±367.43	1581.2±321.73	1721.1±421.03

Number of replications ($n=4$)

Table 3 Sensory attributes of yellow and green pellets as affected by time and temperature of deep-fat frying

Sensory parameter	Temperature (°C)	Yellow pellets- frying time (min)					Green pellets- frying time (min)				
		0.5	1.5	2.5	3.5	4.5	0.5	1.5	2.5	3.5	4.5
Flavor	150	4.8±0.94	7.5±0.83	7.5±1.00	7.8±0.79	8.0±0.64	4.7±1.72	5.7±1.11	7.5±0.98	6.0±1.20	6.3±1.02
	170	7.2±1.20	7.6±1.04	8.6±0.18	7.0±1.07	7.8±0.93	7.7±0.89	8.2±0.34	7.0±0.87	8.0±0.18	7.3±0.88
	190	8.2±0.38	7.8±0.95	7.2±0.80	7.2±1.11	6.0±0.87	8.8±0.01	7.6±0.97	7.4±0.61	4.8±1.00	6.2±0.76
Color	150	7.2±0.67	8.2±0.31	8.2±0.24	8.1±0.20	7.5±0.39	5.5±2.01	6.2±1.78	7.5±0.84	8.0±0.32	6.2±1.49
	170	7.8±0.80	6.9±1.00	7.7±0.21	7.8±0.59	7.7±0.24	8.2±0.32	7.2±0.75	6.0±1.21	7.0±1.04	5.9±1.07
	190	7.3±0.56	9.0±0.00	7.8±0.15	6.3±0.77	6.2±0.85	8.9±0.04	7.2±0.43	6.3±1.89	3.8±1.39	5.1±1.29
Crispness	150	3.7±1.32	5.0±1.08	5.0±2.00	4.8±1.92	5.0±1.04	1.7±0.27	3.7±1.01	4.5±1.69	3.7±0.99	4.3±0.82
	170	7.4±1.11	8.0±1.24	7.2±1.18	7.2±1.70	7.4±0.33	6.5±1.09	7.0±1.24	6.0±1.38	6.0±0.94	7.2±1.16
	190	7.0±1.29	7.4±1.02	7.0±1.23	7.6±1.03	7.5±0.41	7.8±0.83	7.4±1.05	7.4±0.86	7.0±0.73	6.6±1.23
Hardness	150	8.0±1.30	5.0±2.12	5.8±1.89	5.5±1.87	7.3±2.34	8.0±0.19	5.0±1.89	3.5±1.00	7.3±1.48	5.0±1.32
	170	4.6±2.01	5.4±1.93	6.4±2.35	4.0±1.29	3.8±1.31	7.0±1.42	6.2±2.13	7.0±2.01	4.5±1.29	5.8±1.92
	190	3.4±1.79	3.6±2.01	3.2±1.92	4.2±2.01	3.8±1.02	5.5±1.87	5.8±1.24	5.6±0.98	4.8±1.93	4.6±2.10
Adhesiveness	150	3.3±1.41	2.0±0.33	3.0±0.98	3.2±1.02	4.3±2.01	3.3±1.12	3.7±1.75	2.5±0.39	3.0±1.03	4.3±1.39
	170	2.4±0.29	3.6±0.94	3.8±1.23	2.0±0.39	3.8±1.11	5.2±1.89	4.8±1.92	2.0±0.78	2.0±0.48	3.8±1.55
	190	2.8±0.17	3.0±1.14	1.5±0.21	3.6±1.02	4.0±2.03	4.2±2.21	4.4±2.01	4.6±1.59	3.5±0.95	4.2±1.79
Humidity	150	2.7±1.28	1.5±0.13	2.0±0.68	3.0±1.01	3.3±1.13	2.0±0.13	2.7±0.52	2.5±0.43	2.0±0.31	2.7±1.30
	170	1.4±0.97	2.2±0.28	2.2±1.07	2.0±0.28	1.8±0.97	3.2±1.06	3.5±0.68	2.0±0.39	1.5±0.48	1.8±0.23
	190	1.6±0.23	2.0±0.19	1.8±0.56	1.8±0.63	2.0±0.56	2.5±1.17	2.2±0.34	2.6±0.61	1.8±0.92	2.8±1.04
Greasy mouth-feel	150	2.7±0.98	2.5±1.04	2.5±1.14	2.8±0.65	5.0±2.15	2.7±1.02	2.7±0.93	2.0±0.56	3.0±1.04	3.3±0.75
	170	3.4±1.24	4.0±1.32	5.4±2.11	5.0±2.13	5.6±1.97	5.5±1.14	4.8±1.24	2.5±1.03	4.5±1.89	4.7±1.14
	190	3.2±2.00	3.4±1.28	6.7±1.87	4.8±1.80	6.7±1.38	5.0±1.89	4.2±1.72	6.6±2.05	4.5±0.96	5.8±1.83
Total acceptance	150	5.7±1.48	8.0±0.22	7.8±0.73	7.6±0.11	7.7±1.00	4.7±1.23	6.3±1.30	8.2±0.13	6.5±1.20	6.7±1.16
	170	8.4±0.18	7.8±0.78	8.0±0.24	8.2±0.17	7.7±0.87	8.0±0.56	7.7±0.88	7.5±1.04	7.5±0.91	7.4±1.00
	190	8.2±0.19	8.2±0.17	8.1±0.13	7.4±0.87	7.2±1.15	9.0±0.00	7.3±0.60	7.4±0.87	5.2±1.14	7.0±0.98

Number of replications (*n*=6)

time $\times$ temperature, and frying temperature $\times$ snack color were significant ($P < 0.05$) and other factors were not statistically important ($P > 0.05$).

Sensory evaluation

Flavor

As shown in Table 3, no significant difference ($P > 0.05$) in flavor was detected between snacks and panelists scored the flavor of most samples better than average in nine-point scale. Green pellets deep-fat fried at 150 °C for 0.5 min gained the lowest flavor value that was expectable because this condition was not able to expand sample and produce crisp texture. In contrast, yellow products processed at 170 °C for 2.5 min had the most palatability. Temperature of 190 °C at higher frying times diminished the flavor acceptability that could be due to higher oil absorbed and partial burning of samples. Despite non-significant difference ($P > 0.05$) among samples, panelists liked yellow pellets more than the green ones.

Color

One of the most important quality parameters of fried snacks strictly related to consumer perception is the color. Color is critically assessed by consumers and often is the basis for their selection or rejection of products (Mendoza et al. 2007).

Results of ANOVA showed that frying time $\times$ temperature had significant effect ($P < 0.05$) on color acceptance of samples. Generally, the more the frying time, the less the color acceptance of snacks (Table 3). It may be due to decrease in color intensity with puffing of sample during frying as well as influence of higher temperatures and times on burning of snacks. Yellow color snacks obtained more acceptability than the green one; because the fact that at high temperatures some green samples tended to light brownish, while yellow snacks gained the desirable richly yellow color.

Crispness

Crispness is perceived through a combination of tactile, kinesthetic, visual and auditory sensations and represents the key texture attributes of dry snack products. Crispness is also connected with rapid drop of force during mastication process that, in turn, is based on fracture propagation in brittle materials. When force is applied to brittle snacks, rupture of the cellular structure occurs and, in line with some deformation, generates a typical sound contributing to crispness sensation. The crisp materials usually generate irregular force–deformation curve (Mazumder et al. 2007).

As shown in Table 3, increase in frying temperature from 150 °C to 190 °C significantly augmented the crispness of samples ($P < 0.05$). Porous structures developed during puffing play an important role in crispness. The more pores in snacks the more crispness perception (Tsukakoshi et al. 2008). Higher crispness of yellow snacks compared to green ones was also statistically important ($P < 0.05$).

Hardness

To evaluate the hardness of solid foods, the item is placed between the molar teeth and the panelist bites down evenly, evaluating the force to compress the food (Bourne 2002).

Similar to instrumental measurement, panelists' perception of hardness decreased significantly ($P < 0.05$) with increase in frying temperature. Effect of frying time and frying time $\times$ temperature on hardness of samples was not significantly important ($P > 0.05$). Green snacks were harder than the yellow ones ($P < 0.05$).

Adhesiveness

Sensory adhesiveness can be perceived in the palate, teeth, and tongue when the food is being masticated (Adhikari et al. 2001). There was no difference ($P > 0.05$) in adhesiveness scores of snacks that ranged from 1.50 to 5.17.

Humidity

Water content is important in almost all kinds of foods such as fried ones in which water is one of the factors responsible for forming porous and crunchy networks (Shieh et al. 2004).

Sensory scores of humidity ranged from 1.40 to 3.50 that were not significantly different ($P > 0.05$). As expected, panelists perceived the humidity of fried samples low enough.

Greasy mouth coating

The results indicated that significant increase ($P < 0.05$) in greasy mouth-feel occurred when the frying temperature is augmented from 150 °C to 190 °C that is due to higher oil absorption (Table 3). Effects of frying time, frying time $\times$ temperature, and color of snacks on greasy mouth coating were not significant ($P > 0.05$). Oil content has been reported as the major factor affecting the consumer acceptance of fried products (Moreira and Barrufet 1998). These authors stated that bulk density decreases and porosity and oil uptake increase with time during frying of tortilla chips. As moisture evaporates, the void spaces within the tortilla become filled with oil and air.

Total acceptance

The palatability of fried foods lies in their unique organoleptic characteristics, including flavor, texture and appearance (Dana and Saguy 2006). This acceptance is critical because of the specific quality attributes that attract people (Mazumder et al. 2007).

As shown in Table 3, green samples fried at 150 °C for 0.5 min and 190 °C for 0.5 min gained the lowest and highest acceptance, respectively, with mean scores of 4.67 and 9.00. Generally, panelists preferred yellow snacks significantly ($P<0.05$) that could be due to higher flavor, color and crispness values of these samples. Impact of interaction of frying time $\times$ temperature was also statistically important ($P<0.05$).

Correlation instrumental and sensory analyses

In the present study, both instrumental and sensory analyses were considered, since instrumental measurements can provide a quantified basis that is best used as a complement to sensory analysis; and instrumental results can be seen as reliable only if they are validated against sensory evaluations (Shieh et al. 2004). The methodology of PCA was found to be an effective tool in segregating parameters associated with sensory and textural analyses.

In first, possible similarities among the sensory attributes were examined (Fig. 2). According to the PCA biplot three sensory dimensions are discernible: color–flavor – total acceptance, crispness–greasy mouth coating–adhesiveness, and hardness. The third dimension is related to samples fried at higher times and temperature that could be puffed sufficiently and crisp structures were developed in them. Such pellets were also perceived more greasy and adhesive due to

elevated oil uptake at these frying conditions. Besides, this is clearly shown in the PCA biplot that flavor and color were positively and hardness was negatively correlated with total acceptance.

In order to investigate the relationships between instrumental and sensory characteristics, color was excluded, whereas other data were analyzed. The first two principal components (PC1 and PC2) accounted for 73 % of the total variation in the sensory-instrumental data. The first and second PC represented 59 % and 14 % of the variation, respectively. Interpreting the PCA biplot (Fig. 3), three main dimensions were inspected: sensory hardness – apparent modulus of elasticity/fracture force/instrumental hardness/compressive energy, sensory adhesiveness/humidity, and flavor/total acceptance/crispness/greasy mouth coating – instrumental adhesiveness. A more sophisticated point of view of the former dimensions leads to the following suggestions:

- (1) Sensory hardness had positive correlation with apparent modulus of elasticity, fracture force, compressive energy, and instrumental hardness. This result is consistent with findings of Hsieh et al. (2000) who reported good correlation between instrumental hardness and fracturability as well as these parameters with hardness evaluated by human bite.
- (2) Perception of crispness was negatively correlated with instrumental measurements of apparent modulus of elasticity, fracture force, compressive energy and instrumental hardness. This is similar to results of previous studies. For example, Veronica et al. (2006) suggested a good relationship between the results of instrumental texture profile and sensory analyses of puffed extrudates. An increase in breaking strength and hardness and a decrease in brittleness were inversely correlated with consumer perception and

Fig. 2 Principal components analysis of sensory attributes of pellets as affected by frying time and temperature

Fig. 3 Correlation between sensory and texture attributes of pellets deep-fat fried at different temperatures and times

judgment scores of puffiness and crispness. It was also inversely associated with overall acceptability. In another study, brittleness breakdown, the first major peak (or force) at failure before the maximum force is obtained during the first bite and it was introduced as a measure of crispiness (Shieh et al. 2004). Katz and Labuza (1981), by using different types of cutting devices, found that the apparent modulus of elasticity correlated with crispness, stating that the mechanical shear force can be used as indicator of crispness in expanded cereals with low water activity. Good correlations were also found between sensory crispness and the ratio of work to fracture to total work in mechanical test of biscuit (Mallikarjunan 2004).

- (3) Sensory adhesiveness was not correlated well with its instrumental measurement that is in agreement with results of Kim et al. (2009) who found poor correlation between adhesive values from texture profile analysis (TPA) and sensory evaluation of cereal snack bars. Moreover, this result was not entirely unexpected, since adhesiveness to teeth is evaluated by the panelists after the chew down and swallowing, and for dry foods such as pellet snacks, significant amounts of saliva are added before swallowing. Therefore, a compression test cannot be expected to predict a sensory characteristic evaluated after several chews with saliva.

Conclusion

Deep-fat frying conditions played a significant role on the texture and sensory attributes of pellet snacks as it directly affected the crisp behavior, the key factor related to their acceptance. Force-deformation curves obtained through the

uniaxial compression revealed different magnitudes of forces as a function of frying parameters. Sensory attributes of color, crispness, hardness, greasy mouth coating, and total acceptance changed significantly in various frying time or temperatures. Moreover, the PCA results showed a clear relationship between sensory attributes and identified parameters that were closely associated with instrumental texture analysis. Due to the high costs involved in sensory analysis, correlation between sensory and textural attributes is of special importance for food researchers and manufacturers. Further work is needed to understand the details of the sensory perception of texture as well as the instrumental methods that may mimic sensory evaluation.

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