1. Introduction

Firmness is a principal mechanical characteristic for the consumer when eating different solid foods. However, rheological parameters, such as the viscous, elastic and plastic characters of foods are of importance, as well. Compression tests are suitable for determining several mechanical and rheological characteristics of different foods with special respects to consumer perception. Precision penetrometers are used to measure the effect of different treatments, such as storage, drying, freezing, cooking, etc.

The measurement of food firmness is generally performed by precision penetrometer where the compression force is determined as the function of the deformation. With the firmness test the resistance force of the sample is measured relative to the penetration of a flat circular probe. Naturally, several probe shapes and sizes are available.

The measurement of rheological properties is generally performed with respect to the time to determine the elastic and plastic parameters by compression test that includes creep and recovery tests, as well. Consequently, the texture profile of the foods can be determined. This latter one is especially important for the consumer.

We were looking for a hard, a relatively elastic and a mainly plastic food. Therefore, we selected carrots for hard foods, breads for elastic and candy gums for plastic ones.

Vegetables are important components of a balanced human diet and among others provide the consumers with significant levels of some important micronutrients (Vandresen et al., 2009). The consumers are keen on uncooked vegetables, among others on carrot that is an important carotene source. Carrot is very sensitive to storage conditions, especially to temperature and air humidity. The inappropriate storage of carrot causes moisture loss and reduction in the quality. Carrots shrivel, lose the bright orange color and are susceptible to decay. Therefore, it is of great importance to monitor the quality of carrots during postharvest operations (Kaszab et al. 2008).

After harvesting, it is sensible to analyze the small changes of carrots with different destructive and nondestructive methods. The compression test and creep recovery test are suitable for determining several mechanical, rheological and firmness characteristics of different vegetables.

Herppich and co-workers (2002) investigated the effect of the tissue temperature on carrot firmness. Carrot roots were sliced using a microtome blade to a universal testing machine. The roots were placed perpendicular to the blade and the force-deformation curves were evaluated.
The cutting force was analyzed between 0-45°C and the results showed definite decrease in the cutting force with increasing temperature. Corrêa and co-workers (2010) stored carrots in climatic chambers at temperatures of 10, 20 and 30 °C, and the relative air humidity of 45, 65 and 95% during 120 h. The texture was analyzed by penetration test and the diameter of the probe was 10 mm. It was found that the differences in maximum penetration force were significant between the different carrot classes depending on the temperature and the air humidity.

The mechanical properties of bread are a function of the crumb structure (Scanlon and Zghal 2001). Different mechanical and rheological parameters have been used to describe the viscoelastic character of the bread crumb. The creep-recovery characteristic of bread was determined and correlated to the results of sensory evaluation of textural attributes (Carson and Sun 2001). The time for creep and for recovery was the same, 60 s.

The relationship between the sponge structure of starch bread and its mechanical properties was studied and a considerable influence of the large variation in the sizes of cells and thickness of the beams on the Young’s modulus and on the rupture stress was concluded (Keetels et al. 1996/a). The analysis of the structure and mechanics of starch bread (Keetels et al. 1996/b) showed a definite difference between the stress-strain relationship during ageing of potato starch and wheat starch breads. The elastic properties of bread can be analyzed on the basis of the stress-strain relationship with a compression/decompression cycle from which the ratio of the recoverable work is to be determined (Nussinovitch 1992). Most of the changes in the bread crumb occurred during 24 hours after baking. The compression between 30 and 50 % was found to be suitable for the analysis of the elastic properties.

Nowadays the different confectionery products (candy gums, jellies, candy licorices, marshmallows, chewing gums, etc.) are very popular. These products have different shapes, taste and odor. Generally, the candy gum is flavored and colored and formed by moulding. It is soft and elastic, made of sugar, glucose syrup, invert sugar syrup, gelatin and different additives (gum Arabic, etc.). The elasticity is the most important sensory property of candy gums that mainly depends on the quality and the proportion of the different ingredients and additives, especially on the quality and quantity of the gelatin. The candy gum is a viscoplastic material that has to have a definite texture. This texture is dependent on the firmness and on the elastic and plastic characteristics. Therefore, it is very important to use methods suitable for determining the mechanical and rheological characteristics of such products.

The candy gums similarly to other confectionery products are shelf-stable ones that keep their quality for approximately 12-15 months. However, the storage conditions, especially the temperature, have a considerable influence on the quality properties. If the storage conditions are not appropriate, the quality of candy gums will change in a wide range. Therefore, it is necessary to determine the effect of storage conditions on the textural properties of the candies. Further on, it is very important to develop a rapid and simple measurement method for monitoring the quality properties of candy gum during different storage conditions.

Ollku and Rha (1975) made penetration tests and texture profile tests, which were developed by General Foods (so called G.F.T.P. tests) on candy licorice to characterize objectively the textural parameters as the function of sugar, flour and water content. It was determined that the
selection of compression speed and acquisition rate have primary importance for force-deformation testing.

Mitchell (1980) used dynamic experimental methods for investigating the viscoelastic behavior of gels, and emphasized that the rupture tests are not the best for evaluating gels. However, with small deformation compression tests better results can be obtained than with rupture tests.

Örsi et al. (2000) investigated the uncomfortable changes of texture of candy gums with a half-automatic LABOR MIM penetrometer under different storage conditions. The authors determined that the increase of the moisture content caused a decrease in the gel hardness and in the intensity of the bitter flavor.

The objective of the work was to determine the suitability of compression test method for texture analysis of viscoelastoplastic foods. Therefore, the purpose was to determine compression force versus deformation relationship for a hard, a medium hard/soft and a soft food. The tested foods were as follows: raw carrots, different breads and candy gum.

2. Materials and Methods

2.1. Materials and storage conditions

Carrot

Experiments were performed with carrots of cultivar Nantes. The carrots were harvested from fields south of Budapest, Hungary, in November 2010. After harvesting, the carrots were stored under 7,5±1 °C temperature and 85±2% relative humidity. The experiments started on 17 November 2010. Carrots were divided into 5 groups and 9 carrots were in each group. At first, the length, the maximum diameter and the mass of each carrot were measured. The size and mass of the carrots were as follows: 30 to 35 mm diameter, 23.0-29.5 cm length and 0.20-0.24 kg/carrot. Carrot slices were cut with perpendicular to carrot length at the upper 70±5%. Furthermore cube shaped samples were cut out of the both of parts of carrots xylem and phloem and the size of the cube shape samples was 9x9x9 mm. Figure 1 shows the measured parts of carrot.

Figure 1. Measured parts of carrot
Bread

Two kinds of bread with relatively different mechanical properties were involved in the experiments, rye breads containing 70% rye flour and white breads containing 100% wheat flour. Because of lack of gluten the structure of rye breads are more homogenous, the crumb is harder, and less elastic, cells are smaller and cell walls are thicker than that of white breads.

Loaves were stored at ambient temperature covered with linen towels. Breads were cut to 15 mm thick slices before measurements, the first 3 slices of the both ends of the loaves were left out of measurements. In case of white bread the number of samples was in average 11 while in case of rye bread it was 8 slices/bread.

Candy gum

For the short time storage experiments the commercial candy gums were received from a local dealer and were of the same brand. The samples were stored in the original package in temperature controlled storage boxes for 72 hours at different temperatures from 14°C to 32°C with 2°C intervals and at 50%±10% relative air humidity. The temperature of the storage boxes was controlled by a programmable relay between ±0.5°C range, and temperature data were recorded by a data logger in every 20 seconds. The sample packages were opened directly before the measurement. During the rheological tests the samples were stored in a thermostat to avoid the temperature changes of the samples.

2.2. Methods

Cutting tests and compression tests were performed with Stable Micro System TA-XT2 Texture Analyzer. The cutting speed was 0.1 mm/s and the speed of the probe was 1.0 mm/s before and after the measurement at the cutting test. The cutting force was measured and the specific cutting force was calculated from the ratio of the maximum cutting force to the cutting diameter at the cutting method. At the compression tests the penetration speed was 0.2 mm/s with different probes depending on the material of the tested sample. However, the speed of the probe was 1.0 mm/s before and after the measurement (compression and decompression), respectively. The maximum compression force and the deformation were determined according to the character of the tested material (Figure 2).

Figure 2. The TA-XT2 Texture Analyzer instrument
The results of the tests performed with the texture analyzer were recorded and evaluated by the Texture Expert 1.22 software. The variables and parameters were calculated by macros written in the same software and the processing and evaluation of the data were done by MS Excel 2003 software.

**Carrot**

The cutting and compression measurements were performed with one week intervals. The mass of each carrot of the different groups were measured at the beginning of the storage period and at the end of each week during the five weeks storage.

The cutting force tests were carried out with a sharp blade of 3 mm thickness (from the SMS set). The motion of the blade was perpendicular to the surface of the 5 mm thick carrot disks. These disks were cut out of the carrot at the 1/3 of length from the top end. The disks were cut along its diameter with 0.1 mm/s cutting speed. Three cutting tests were performed on each carrot. The specific cutting force was calculated from the ratio of the maximum cutting force to the cutting diameter.

Creep-recovery test (CRT) is a combinative measurement method that includes three stages. In the first stage the sample is compressed with a definite force (it was equal with the maximum force, which was needed to reach the 25% deformation rate). When the force reaches the definite value, the load is kept constant for a definite time. This is the creep stage. At the end of the creeping the load is suddenly reduced to zero. Then the force is kept at zero. This is the recovery stage that generally lasts for the same time as the creeping. During the CRT the force, the deformation and the time values are recorded.

The creep-recovery test was performed with a definite carrot group at the end of each week during the storage period. The texture analyzer was fitted with a cylindrical metal compression plate of 75 mm diameter for these tests. The measurement parameters were, as follows: the compression force was 60 N, the time for both the creep and the recovery stages was 60 s. The acquisition rate of the precision penetrometer was 100 points pro second.

**Bread**

In case of bread creep-recovery test was carried out with a Stable Micro Systems TA-XT2 texture analyzer, fitted with a 35 mm diameter cylindrical flat probe. For the measurement a build-in sequence named “Relaxation test” was loaded. The sequence of events performed by the program is, as follows:
- the force was increased up to 5N
- this force is held for 60s
- the probe was retracted to the start point, approximately zero force
- this zero force is held for 60s and the deformation of the product was recorded.

The pre- and post-test speed of the probe was 2 mm/s, the test speed was 0.2 mm/s during measurements, the acquisition rate was 100 points pro second.
Candy gum

To describe the effect of storage temperature on the rheological properties of candies creep-recovery tests (CRT) and Texture Profile Analysis (TPA) were performed. Both tests were performed with the Stable Micro Systems TA-XT2 texture analyzer. The probe used was a cylindrical metal compression plate of 75 mm diameter. Therefore, the area of the probe was bigger than the surface of the samples to be measured.

The CRT tests were performed with constant 5 N loading force. This force value was determined from earlier experiments, in which the force was needed to reach a relative deformation of approximately 50%. Both the creep and the recovery time was 60 s. During the creeping the load was constant, 5N, but after the creeping the load was decreased to zero immediately and during the recovery it was constant zero. The maximum deformation was recorded at the end of the creeping. The acquisition rate of the precision penetrometer was 50 points pro second to decrease the errors that could occur because of the very small values of the force.

3. Results and Discussion

3.1. Carrot

Close linear correlation was found between the ratio of the compression force (F) to the deformation (D) and mass loss in a very wide range of the mass loss for the carrots (Figure 3). Difference was not found between xylem and phloem part of carrots. The tendency of the change was the same for xylem and phloem.

Figure 3. The ratio of force to deformation as the function of the mass loss for carrot part of xylem and phloem

![Figure 3](image)

The maximum compression force was determined for the xylem and phloem parts of the carrots versus the mass loss. Figure 4 shows a definite decrease in the ratio of force to maximal
deformation as the function of the mass loss. Close correlation was found between the variables for all storage groups. The measured points of xylem part of carrot are higher than that of phloem part.

Figure 4. The ratio of force to maximal deformation as the function of the mass loss for carrot part of xylem and phloem

![Graph showing deformation vs. mass loss for carrot parts.](image)

\[
y = -0.2326x + 38.217 \quad R^2 = 0.9065
\]
\[
y = -0.1686x + 27.403 \quad R^2 = 0.98
\]

3.2. Bread

During storage bread undergoes several physical, sensory and microbial changes that cause loss of freshness. These changes result in hardening of the crumb and softening of the crust and cause changes in the attributes. Drying and bread staling are the most important factors of quality reduction. As the bread crumb ages, the amount of force required to compress the crumb increases. It means that applying a definite force causes less deformation. This is shown in Fig. 5 where the ratio of force to the total deformation is versus the storage time for white and rye bread.

Figure 5. The ratio of force to maximal deformation as function of the storage time for white and rye bread

![Graph showing force vs. storage time for bread.](image)

\[
y = 0.033x + 1.1797 \quad R^2 = 0.9631
\]
\[
y = 0.0167x + 0.4513 \quad R^2 = 0.9812
\]
3.3. Candy gum

The texture of the candy gums changed in a wide range as the function of the temperature. Figure 6 shows that there is a definite linear decrease in the ratio of force to deformation when taking into account the maximal force deformation at the end of the force increasing period. Therefore, there is a definite reduction in the firmness versus the temperature. There was a close correlation between the variables. However, the deviation in the measurement points increases with higher temperatures, especially above 22°C.

Figure 6. The ratio of maximal force to deformation (F/D) at the end of the force increasing period. as the function of storage temperature of candy gum

![Graph showing the ratio of maximal force to deformation](image)

\[
y = -0.0141x + 1.4745 \\
R^2 = 0.8828
\]

Figure 7 shows the ratio of the maximal force to the maximal deformation as the function of the temperature at the end of the creeping period. The deviation in the measurement points is similar to that of the Figure 9 and it increases with higher temperatures, especially above 22°C.
Figure 7. The ratio of force to maximal deformation (F/D_{max}) at the end of creeping as the function of storage temperature for candy gum.

4. Conclusion

The ratio of the compression force to the deformation with carrots showed a definite decrease as the function of the mass loss. That means that carrots became softer during the storage.

With breads the ratio of the compression force to the deformation showed a considerable reduction versus the storage temperature. This means a definite hardening that was bigger with rye breads than with wheat ones.

With candy gums the ratio of the compression force to the deformation showed a definite decrease as the function of the storage temperature.

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