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TEXTURAL PROPERTIES OF FRUITS AND VEGETABLES AND THEIR CHANGES DURING FREEZING AND STORAGE AT LOW TEMPERATURES

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Abstract

Five sour cherry varieties (Pándy, Érd, Meteor, M63 and M136), four apple varieties (Starkrimson, Idared, Goldenspur, Jonathan), two peach varieties (Elberta and Champion) and two pear varieties (Hardy and Alexander) grown in Hungary were investigated. Changes of commercial carrots during pretreatment and freezing were also studied.

Textural properties were studied during ripening, freezing and thawing using the texture profile method of SZCZESNIAK et al. (1963), penetrometric measurement (LÁSZTITY et al., 1973) and organoleptic control.

Both the penetrometric and organoleptic methods were found to be satisfactory for classifying the fruits of different degree of maturity. Textural changes occurring during freezing were strongly affected by the variety and also by maturity degree. Frozen and thawed products were always softer than fresh products and this was valid also for the texture after cooking. A chilling of sour cherries before freezing and immersion of some vegetables into a solution of lower pH decreased textural changes during freezing.

Keywords: fruits, vegetables, texture, freezing, sour cherry, apple peach, pear, carrot.

Introduction

Among the different possible ways of the preservation of foodstuffs freezing is the best available method. Food preserved by other means may be equally acceptable and of high nutritional value, but the properties of frozen products are the closest to those of fresh products.

In freezing preservation of fruits and vegetables, the rate of postharvest biochemical changes is retarded and microbial deterioration inhibited. Thus this procedure has the smallest possible effect on the natural properties of the fresh product. However, comparison of fruits and vegetables which are usually eaten uncooked after freezing and thawing with untreated fresh samples of the same product reveals appreciable differences. These differences are mainly connected with the changes of the texture. The changes are associated with the destruction of life in plant tissue by industrial freezing. Raw fruits and vegetables have living cell tissue with a well regulated metabolism. On the other hand, the industrially frozen plant products especially if enzyme inactivating pretreatment is applied are dead and as a consequence unable to maintain concentration and pressure differences in their cells. The specific changes connected with the loss of cell life limit the retention of the natural quality of fruits and vegetables by freezing. This was taken into consideration when the industrial freezing preservation of fruits and vegetables was developed.

How far the natural quality of fruits and vegetables can be retained after freezing preservation depends on many factors. Some of them are listed as follows:

- type and variety of the fruits or vegetables
- maturity and the quality of raw product
- the amount of handling between harvesting and processing
- the treatment before freezing and the technology of freezing
- storage time and temperature
- thawing procedure

In the framework of this paper the changes of the texture, as the main quality factor will be discussed.

The Texture of the Fruits and Vegetables

The textural properties of the fruits and vegetables are influenced by many factors, nevertheless three factors are the most important:

- the microstructure of the tissue
- turgor pressure
- adhesion forces between the cells

The bulk of the fruit and vegetable tissue is composed of parenchyma cells having a polyhedral shape. Depending on the structure, the tissues contain 1 to 25 % air. At maturity the cell walls are relatively thin and their shape results in the formation on intercellular spaces. Each cell is cemented to the next one by an amorphous outer pectin-rich middle lamella. The cell wall consists of alternating layers of cellulose microfibrils embedded in a substance mainly consisting of hemicelluloses with some proteins. Within the cell wall is located the protoplasm consisting of outer citoplasm membrance, citoplasm, cell nucleus. The presence of a big vacuole surrounded by membrane is mainly also characteristic. This vacuole contains minerals, sugars and other components in solubilized form and in some cases also starch granules.

If the cells are relatively small and also the intercellular spaces are small, the texture is generally firmer. Oppositely, bigger cells and intercellular spaces are connected with a softer fruit structure (REEVE, 1970). From the point of view of the texture the properties of the cell wall and middle lamella are decisive. It is generally accepted that the strength of the cell wall depend mainly on the cellulose content and its structure. The properties of the middle lamella depends mainly on the physicochemical properties of pectin molecules (degree of polymerization, etc.).

The turgor pressure keeps the protoplasm pressed against the cell wall and this helps to maintain the tissue's firmness. The turgor pressure is connected with the physiological processes of cells, so it does not play a role in the dead cells.

Changes During Ripening and Storage

A large number of physiological and biochemical changes occur during the ripening of fruits and vegetables. The progressive increase in softness of the tissue together with a change in colour of the skin or flesh, and the production of a wide spectrum of aroma compounds are some of the most easily recognisable changes that accompany the ripening of fruits.

From the point of view of textural properties the processes changing the properties of the cell wall and middle lamella are the most important. Some of these changes are connected with the mechanical effect caused by the growing and swelling of the fruits. In a typical climacteric fruit such as tomato, increase in size is by cell division in the first period and then after fourteen days by cell expansion. During the next few weeks partial separation of the cell wall at the middle lamella occurs but this is probably caused by rapid cell expansion and at the same time contact is lost with adjacent cells to form intercellular spaces. This incipient separation is thought to be mechanical in origin rather than enzymatic. Near ripeness the pericarp cells become very large and cell separation much more complete. The greatest part of the modifications is caused by a series of coordinated enzymatic transformations.

Before considering some of the properties of the enzymes involved in softening we return to the components of the cell wall. A number of recent reviews are available on this topic (ROBINSON, 1977, HALL, 1981, KNEE, 1981). In summary it can be stated that the pectin substances are thought to consist of a neutral homogalacturonan (See *Fig. 1*, HOBSON, 1981) and perhaps surrounded by a protecting coat of arabans and galactans or a polymer containing both sugars. The hemicelluloses consist of xyloglucans and glucuronoarabaxylans non-covalently associated with

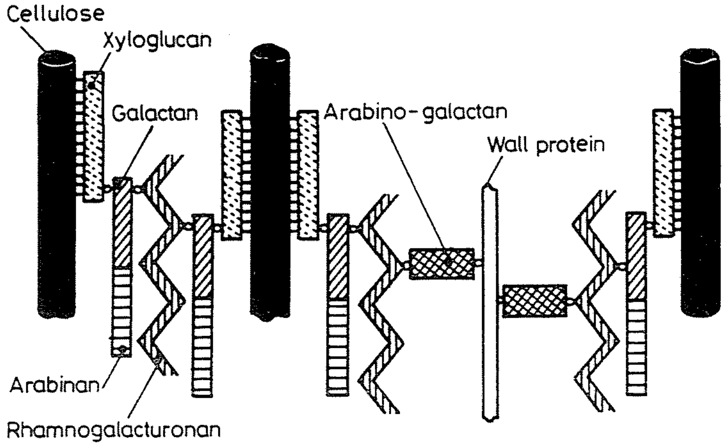

Fig. 1. Suggested scheme for the structure of fruit cell wall (HOBSON, 1981)

cellulose. The proteins are rich in hydroxy-proline. Cellulose fibers are closely allied to hemicellulose to which they are hydrogen bonded, and the cellulose-hemicellulose complexes are interconnected by a network of pectic polysaccharides probably with protein attachments, and all these form the primary wall of the cells.

The enzymes playing a role in the modification of the cell wall and middle lamella are first of all pectin degrading enzymes. The possible interrelations between the various factors that transform a hard, unripe fruit cell into a much more attractive form is illustrated in *Fig. 2*. The more general changes in the texture are thought to result from sequential attacks on the protopectin polymer. Initially the pectin-methyl-esterase (PME) glycosidases and glucanases are the most active enzymes. In the next period parallel with the rise in respiration a rapid synthesis of the polygalacturonase (PG) was observed. Calcium in soluble form is released in this time and also carbohydrates containing galactose and arabinose. It was supposed that this then opens the way for the liberation and degradation of the water soluble pectic substances, erosion of the middle lamella, disintegration of the primary cell wall and much more extensive loss of tissue firmness.

Results of some recent investigations suggest that in addition to degrading pectic substances of the middle lamella and cell wall, polygalacturonase has also a role in the release of protein, part of which could be inactive while bound to the cell wall and on desorption could be involved in promoting the ripening. The involvement of other hydrolytic enzymes in addition to polygalacturonase in texture changes during ripening of fruits

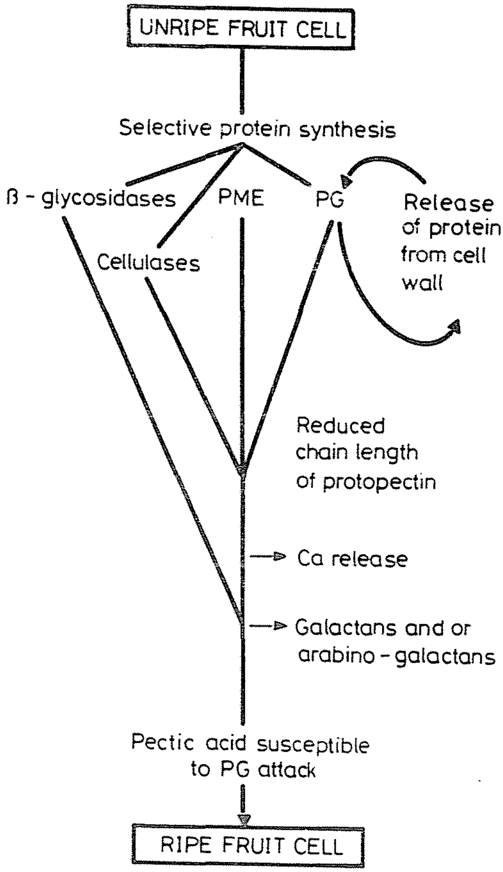

Fig. 2. Tentative scheme outlining the enzymes responsible for texture changes during the ripening of climacteric fruits (HOBSON, 1981)

seems very likely. Beta-glycosidases are present in many fruits and cellulose activity was also detected. On the other hand, the quantities of hemicelluloses and cellulose do not decline during the ripening of many fruits. Nevertheless it was suggested that although there may not occur quantitative changes in hemicelluloses, solubilization of this fraction is associated with increased wall plasticity.

Measurement of the Textural Properties of Fruits and Vegetables

Many reviews are available concerning rheology and food texture (DE MAN et al, 1976, SHERMAN, 1979, SEBŐK, 1980). Among the methods most widely used the following ones are the most important:

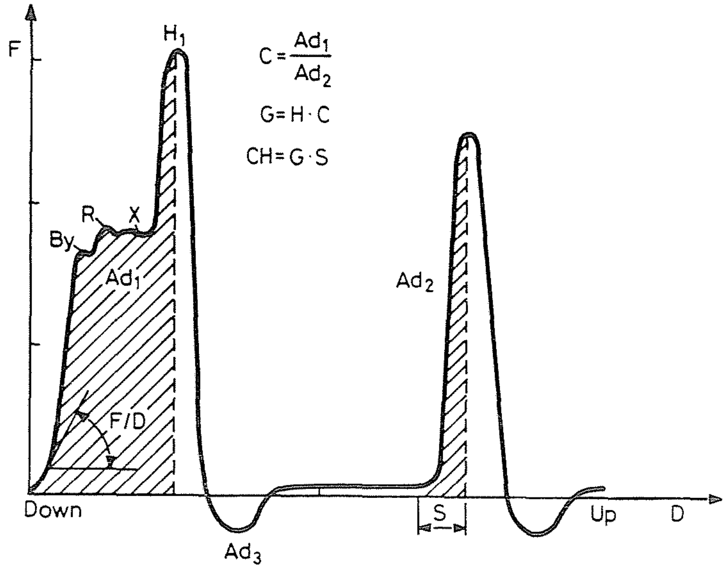

Fig. 3. Typical force-deformation curve obtained by texture profile method

- penetrometric (puncture test) methods
- texture profile method (SZCZESNIAK, et al. 1963)
- extrusion methods
- viscosimetric methods
- indirect methods.

Penetrometric and puncture test methods belong to the simplest methods and are widely used in practice. Mostly the maximal force needed for the penetration of the deforming body to a given depth is measured.

The texture profile analysis method is widely used in research work and in many cases in industrial laboratories. The fruit sample is compressed between parallel plates imitating the chewing and the process is repeated. A typical force-deformation curve registered is shown in *Fig. 3*. On the basis of the evaluation of this curve the following values may be determined:

By - biological yield value
H - hardness
Ad_1 - work of compression
Ad_2 - work of repeated compression
C - cohesivity = Ad_1/Ad_2
S - elasticity
Ad_3 - adhesivity
G - gumminess = HXC
CH - chewiness = GXS.

Especially the biological yield value and the hardness are characteristic of the texture. Extrusion methods are mostly used for texture measurements on pieces of irregular shape or for the simultaneous evaluation of a lot of pieces (e.g. green peas). The viscosimetric methods generally serve for the evaluation of the consistency of processed fruits and vegetables. The indirect (optical, ultrasonic, etc.) methods at this time are in an experimental stage and probably may play a role in the future.

Changes during Freezing

The effect of freezing on the living cells and tissues has been very thoroughly studied recently by researchers dealing with the field of cryobiology. To which extent scientific knowledge of low temperature biology is being applied in current industrial practice is discussed by specialists of food research and food technology and some good reviews were published (HAWTHORNE and ROLFE, 1968, FENNEMA et al, 1973, BOURNE, 1976). Without going into details, some of the main features of the changes will be summarized.

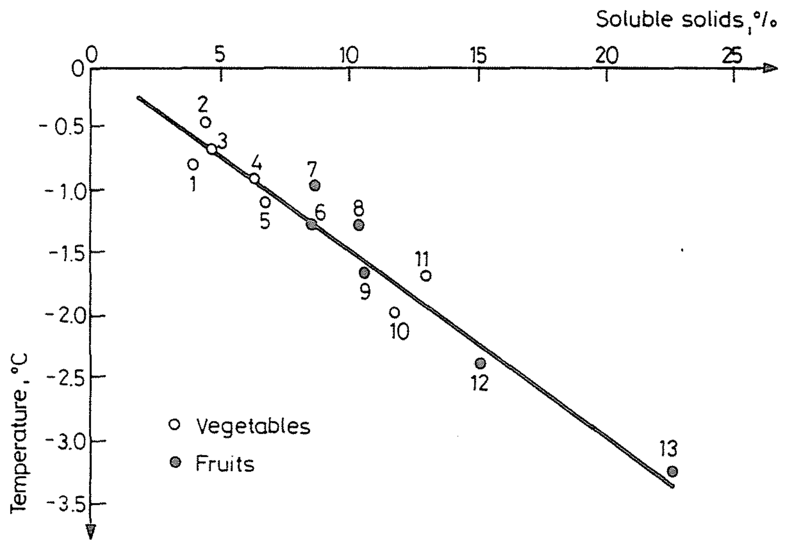

Fig. 4. Freezing points of some fruits and vegetables in relation to their content of soluble solids

The temperature at which the water in a plant products begins to freeze depends on the content of soluble substances in the citoplasm (see *Fig. 4*). Because of the wide range of soluble solids the freezing of fruits

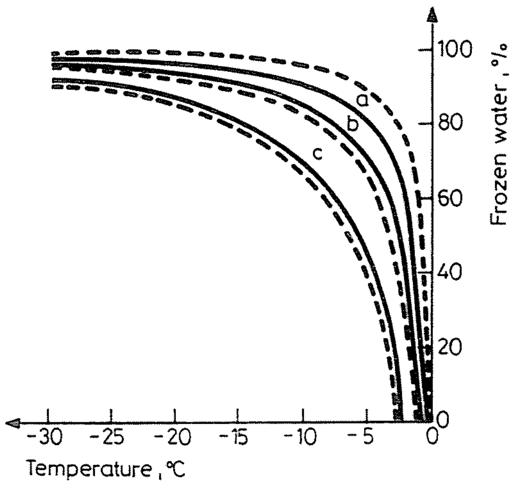

Fig. 5. Percentage of water frozen out in some fruits and vegetables

and vegetables begins at a temperature of –0.5 °C to –3.5 °C. Most plant tissues need supercooling before nucleation occurs and the formation of the ice crystals begins. In immersion freezing of single fruits supercooling down to –9 °C was measured. In industrial freezing of packaged homogeneous products supercooling will be found only near the surface.

Bearing in mind that the cell content of the fruits and vegetables is a dilute solution at the temperature below freezing point pure ice will be formed causing the remaining solution to be more concentrated and to have deeper and deeper freezing point. Most of the water freezes near the freezing point (see *Fig. 5*). The freezing is practically completed somewhere between –30 °C and –40 °C. The amount of water not frozen at this temperature and even at lower temperatures in fruits and vegetables is of the order of 0.2–0.3 kg/kg dry substance. The process of the ice formation was thoroughly studied by many authors and many excellent reviews are published in this field. The conclusions may be summarized in the simplest way as follows:

- the freezing of water begins in the intercellular spaces, if the rate of freezing is low there is enough time for a water transport from the inner part of the cell to the intercellular spaces and bigger ice crystals may be formed, at the same time a concentration change of the cytoplasmic components occurs causing irreversible changes in the cell and its metabolism
- oppositely by a faster freezing this water transport is impossible, a more homogeneous structure will be formed.

The influence of the freezing rate on the quality of frozen fruit and vegetable products has been the subject of extended research work. In all publications and reviews the advantages of quick freezing were pointed out.

Nevertheless some experimental data show that within certain limits the rate of freezing does not affect the quality of most foods to any great extent. It seems that generally a freezing rate above 0.5 cm/h is satisfactory for foods in retail packages, although higher rates may be chosen for economic reasons. From the point of view of the evaluation of different freezing processes very interesting results were published by JUL (1982). This author pointed out that the effect of the freezing rate is significant only with the products frozen in pieces of small size. In the case of freezing of bigger pieces this effect is of a smaller extent and in many cases there are no substantial differences between the different freezing procedures.

In the framework of experiments made in the last years at the Department of Biochemistry and Food Technology at the Technical University of Budapest and Laboratory of the Hungarian Frozen Food Industry the role of the following factors was investigated:

- effect of variety
- effect of maturity
- pretreatment before the freezing
- storage temperature and time.

Materials and Methods

Five sour cherry varieties (Pándy, Érd, Meteor, M63 and M136), four apple varieties (Starkrimson, Idared, Goldenspur and Jonathan), two peach varieties (Elberta and Champion) and two pear varieties (Hardy and Alexander) grown in Hungary were investigated. A commercial carrot sample was also the object of studies.

For the determination of textural properties the texture profile method of SZCZESNIAK et al. (1963), penetrometric measurement (LÁSZTITY et al., 1973), method of SCHOORL and HOLT (1980) resistance of skin (LÁSZTITY and VOISEY, 1973) and organoleptic evaluation according to the Hungarian Standard were used. A detailed description of all the methods was given by SEBŐK (1983) and LÁSZTITY et al. (1973).

Results and Discussion

Effect of Variety on Textural Properties and Their Changes

Five sour cherry varieties grown in Hungary (Pándy, Érd, Meteor, M63 and M136) were investigated. The texture of the raw fruit and the frozen and thawed product was measured on the basis of biological yield value and the force needed for the breakage of fruit skin. The variety Pándy was superior to other varieties. As a final conclusion it was stated that the effect of variety is one of the most important ones, therefore the breeding and selection of new varieties more suitable for freezing might be the main direction of further research work. From the biological point of view the investigation of the genetic background of the suitability for freeze processing may also be of interest.

Degree of Maturity

A comparative study of penetrometric and organoleptic methods for measuring the degree of maturity of different fruits was carried out. Some of the results are summarized in *Tables 1* and *2*. The fruits were, on the basis of sensory evaluation of one experienced person, classified into five groups of maturity degree. After that a group of 10 persons scored all the pieces of fruits (1 = unripe; 5 = fully ripe). Averages of scores are summarized in the tables. As it is shown the 'separating power' of the penetrometric method is practically the same (or in some cases better) as that of the organoleptic method.

In the case of sour cherries it was shown that if the fruits were hand harvested the full maturity of the sour cherries was the optimal in respect of the textural properties of the end product. An improvement of the texture was observed during the last period of the ripening. These phenomena may be eplained by assuming that the softening effect of the degradation of pectic substances in overcompensated by the increase of turgor pressure.

The mechanically harvested fruits showed an optimal texture, in relation to the properties of quick frozen sour cherries after thawing, at a maturity of 80–90 %. This fact may be explained by assuming that the mechanical injury of the single fruits of higher degree of maturity is significantly higher.

Table 1
Comparison of measurement of maturity degree of peach variety Elberta by penetrometric and organoleptic methods

Organoleptic evaluation		Penetrometric measurement (penetration in mm-s)
Maturity class	Average score (d. f. = 90)	Average value (d. f. = 90)
1.	1.167	0.4325
2.	1.667	1.075
3.	3.167	1.181
4.	4.500	1.585
5.	4.833	1.515
	Significance of the difference between classes (0.05 level)	Significance of the difference between classes (0.05 level)
1–2	no	yes
1–3	yes	yes
1–4	yes	yes
1–5	yes	yes
2–3	yes	no
2–4	yes	yes
2–5	yes	yes
3–4	yes	yes
3–5	yes	yes
4–5	no	no

Changes during Pretreatment and Freezing

A beneficial effect of chilling before blanching and freezing was observed. A temperature of chilling of 4 °C to 6 °C was found to be optimal. Reduced blanching time and temperature had also advantages in relation to textural properties. Especially in the case of vegetables a treatment with solution of lower pH could be effective in decreasing of microbial count without adverse effect on the texture.

Concerning the effect of blanching (cooking), freezing and thawing, in *Table 3* some results measured with carrots are summarized. Penetrometric and organoleptic data are shown (1 – characteristic of the raw material, 4 — optimal consistency after cooking, 5 and more – too soft). As it is shown by *Table 3*, freezing and thawing causes a partial softening of carrots. The

Table 2
Comparison of measurement of maturity degree of peach variety Champion by penetrometric and organoleptic methods

Organoleptic evaluation Maturity class	 Average score (d. f. = 90)	Penetrometric measurement Average penetration in mm-s (d. f. = 90)
1.	2.500	1.024
2.	3.500	1.490
3.	3.667	1.502
4.	4.167	1.536
5.	5.000	1.901
	Significance of the difference between classes (0.05 level)	Significance of the difference between classes (0.05 level)
1–2	yes	yes
1–3	yes	yes
1–4	yes	yes
1–5	yes	yes
2–3	no	no
2–4	no	no
2–5	yes	yes
3–4	no	no
3–5	yes	yes
4–5	no	yes

frozen carrots became softer after cooking than the raw material suggesting that structural changes take place during freezing.

Storage Temperature and Time

The advantage of lower storage temperatures (–20 °C and lower) was demonstrated. The stability of temperature is an important factor in the preservation of good quality in contradiction to some views that fluctuating temperature does not affect the quality of the products.

The HQL (high quality life) of different products stored at –20 °C ranged from 6 months to 2 years. After this period a significant deterioration of the textural properties was observed.

Table 3
Changes of consistency of carrots as affected by different treatments
(Averages of 42 samples)

Treatment	Organoleptic scores	Penetrometric data (PM - units)
Raw carrot	1.05	1.52
Frozen carrot after thawing	1.37	8.81
Raw carrot after cooking for 20 min.	1.67	7.4
Frozen carrot after cooking for 20 min.	4.66	11.7
Raw carrot after cooking for 60 min.	1.92	9.8
Frozen carrot after cooking for 60 min.	5.33	over 30

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