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Sodium chloride and vegetables

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Summary
Cooked vegetables have a long history. Vegetables consist of plant cells. Plant cells have walls that are permeable for water and gases, but not for starch and salts. The walls are stiff and composed of a framework of fibres of cellulose, with imbedded hemicellulose and pectin. In the cooking process these imbedded structures dissolve and make the plants cells permeable so that ions can leach out of the cells. The hypothesis is that this process is temperature dependent. To test this hypothesis four portions of green beans were separately brought to 60, 70, 80 and 95 °C in a 0.1 mol/L NaCl solution and kept at that temperature for 5 minutes. A higher temperature results in an increase in the amount of Cl^- ions leached out of the plant cells. Further inquiry is needed on the nature of the relation between the temperature and the leached out amount of NaCl.

Plant cells, cell wall, dissolving, temperature, titration, concentration

Introduction

Long back people started eating cooked vegetables. Recipes from the 17th century show the preparation of fine sauces together with cooked vegetables (1).
Vegetables are plants. Plants are built up of plant tissue that is composed of cells (see Figure 1).

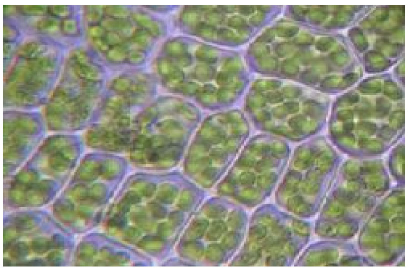
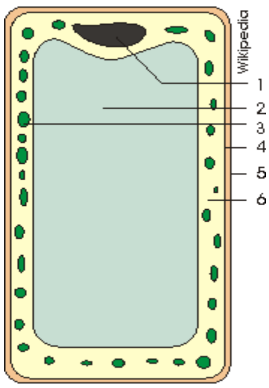


Figure 1: Plant tissue with cells

Plant cells contain various parts (see Figure 2). The cell walls (see Figure 2, part 5) give texture to the plant cells. These walls are on the contrary to the cell membranes stiff and not very flexible. The nature of the cell walls and the presence of water determines the texture of vegetables. Cell walls are permeable for water and gases, but not for starch and salts. Plant cells can take up water until the moment that the cell membrane presses against the stiff wall; turgor pressure. Then the vegetables are 'crispy'. When vegetables loose water then they wither and the vacuoles are shrivelled and the membranes are moved away from the walls. The most important part of the cell wall is cellulose (2). This cellulose is an organic compound with the formula $(C_6H_{10}O_5)_n$.



1. Nucleus
2. Vacuole
3. Chloroplast
4. Membrane
5. Wall
6. Cytoplasm

Figure 2: Plant cell with six indicated parts.

Cellulose is indigestible by humans; the fibres. These fibres serve as a framework for hemicellulose and pectin (see Figure 3) containing substances.

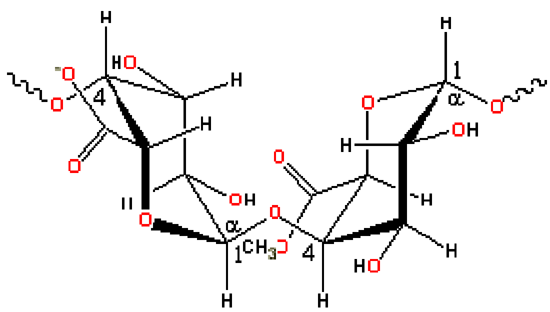


Figure 3: Part of the molecular structure of pectin.

Hemicellulose is a polysaccharide that has a random amorphous structure with little strength and is easily hydrolyzed by dilute acid or base solutions (3). The pectin containing substances play an important role in the ripening of the vegetables. During the ripening process the pectin dissolves and the cell walls become softer. This softening process also is seen when vegetables are cooked. A softening that occurs because hemicellulose and pectin containing substances dissolve in the cooking water (4). Thus the wall structure changes and probably allows salts that are in the plants' vacuoles to escape.

Therefore the research question is: *what amount of NaCl is leached out of plant cells when heated at different temperatures in a common salt solution?*
Our hypothesis is that dissolving depends on the temperature and the higher the temperature the more NaCl will be leached out. We expect a linear relation.

Experimental procedure and approach

32.70 g NaCl (s) was made up to 5.00 L in distilled and deionised water. A solution of salt water that contained the amount of salt usually used for cooking. To check the NaCl concentration three 10.00 mL portions of this stock solution (S_0) were titrated (5) with 0.05 mol/L silver nitrate solution with a few drops of potassium chromate indicator; Mohr method. Then four 2.5 L beakers were each filled with 1 L of the NaCl stock solution. Moreover, 130 g fresh green beans were added. Each beaker was brought to the right temperature – respectively 60, 70, 80 and 95 ^oC – and kept at that temperature for a further 5 minutes. The four 'cooking' waters were then filtered off in different 1 L measuring cylinders. The volume in mL of the four recovered solutions (S_1-S_4) were determined. Then three portions of 10.00 mL of the recovered water out of each cylinder were titrated with 0.05 mol/L silver nitrate solution with a few drops of potassium chromate indicator. For each series of titrations the titres were averaged. These averaged titres were plotted against the temperature in a graph. Then the grams of NaCl in the recovered solutions (S_1-S_4) were calculated and compared to the grams of NaCl in the stock solution (S_0).

Results

In the titration of the NaCl stock solution (S_0) with the silver nitrate solution the indicator turned from yellow to red. Table 1 presents the three obtained titres and an averaged titre of 12.16 mL.

NaCl stock solution (mL)	$AgNO_3$ solution (mL)
10.00	21.20
10.00	21.12
10.00	21.16
Average: 10.00	21.16

Table 1: $AgNO_3$ titres (mL) in the three titrations of 10.00 mL of the NaCl stock solution (S_0).

In all four beakers the heated beans became softer and changed colour from green to brown. The recovered solutions (S_1-S_4), or filtrates, in the four measuring cylinders were all close to 1 L. Table 2 shows the obtained averaged titres for the titrations of 10.00 mL of the recovered solutions (S_1-S_4).

Solution: averaged (mL)	Averaged titres of $AgNO_3$ (mL)
S_1: 10.00	22.20 ± 0.02
S_2: 10.00	22.33 ± 0.06
S_3: 10.00	22.59 ± 0.02
S_4: 10.00	22.72 ± 0.03

Table 2: Averaged $AgNO_3$ titres in mL in the three titrations of 10.00 mL of the recovered solutions S_1-S_4.

Figure 4 shows the averaged measured titres of the recovered solutions (S_1-S_4) against the used temperatures of 60, 70, 80 and 95 ^oC.

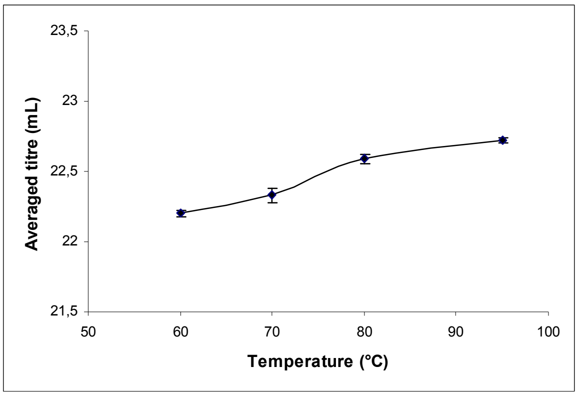


Figure 4: Averaged measured titres (mL) against temperature (^oC).

Data analysis

The three 10.00 mL portions of the NaCl stock solution (S_0) were titrated with 0.05 mol/L silver nitrate solution. Table 1 shows that in average 21.16 mL of this silver nitrate solution is needed. Thus there are 21.16 mL x 0.05 mmol/mL = 1.0580 mmol Ag^+ present. Ag^+ ions react in the ratio 1 : 1 with Cl^- ions. Therefore there will be as well 1.0580 mmol Cl^- ions present, but now in 10.00 mL. This gives the concentration of Cl^- in the stock solution (S_0) as 1.058 mmol in 10 mL or 0.1058 mol in 1 L. So there was 0.1058 mol/L x 58.5 g/mol x 1L = 6.19 g NaCl in the stock solution (S_0).
Table 3 presents the moles of Cl^- in 10.00 mL of the stock solution (S_0) and in 10.00 mL of the four (S_1-S_4) recovered solutions (0.05 mol/L x averaged titre/1000 x L) as well as the amount in grams of NaCl (mol x 58.5 g/mol x 100) in 1L of the stock solution (S_0) and the recovered solutions (S_1-S_4). Moreover, the comparisons of the amount of grams of NaCl in the recovered solution (S) and the stock solution (S_0) is shown.

Conclusion and discussion

The results (Table 3) of the titrations of the stock

Solution	Moles Cl^- in 10.00 mL	Grams NaCl in 1 L	S_x-S_0 in grams
S_0	1.058 x 10^{-3}	6.19	0
S_1	1.110 x 10^{-3}	6.49	0.30
S_2	1.117 x 10^{-3}	6.53	0.34
S_3	1.130 x 10^{-3}	6.61	0.42
S_4	1.136 x 10^{-3}	6.65	0.46

Table 3: Moles of Cl^- in 10.00 mL and grams of NaCl in 1L of the stock solution (S_0) and recovered solutions (S_1-S_4) as well as the difference in amount of grams between each recovered solution (S) and S_0.

solution (S_0) and the recovered solutions (S_x) show that the amount of grams of NaCl in all solutions (S_1-S_4) compared to the S_0 solution has increased. These results certainly do support the hypothesis that plants cells of green beans, or may be of vegetables in general, leach out Na^+ and Cl^- ions when heated in a NaCl solution that has an amount of salt that usually is used for cooking vegetables. Thus it can be concluded that Na^+ and Cl^- ions have leached out of the plant cells during the heating process.

Moreover, increase of the temperature of the stock solution from 60-95 ^{0}C shows (Figure 4) that the amount of Na^+ and Cl^- ions leaching out of the plant cells increases as well.

The observation that the green beans become softer in a heated salt solution supports the explanation that parts of the cell walls like hemicellulose and the pectin containing substances dissolve (4) and as such create room for ions to leach out from the vacuoles through the walls of the plant cells. A process that is temperature dependent and probably has a S-shaped dependency. Further inquiry is needed to find the nature of the relation between temperature and amount of Cl^- ions leaching out of plant cells, because the titre readings around 70 ^{0}C seem to be not very reliable.

The observation that in the heating process the beans change colour from green to brown, can be explained by the change in chlorophyll-*a* molecules (see Figure 5) in the chloroplasts of the plant cells.

Chlorophyll-*a* has a porphyrin ring system with an Mg^{2+} ion (indicated in green see Figure 5) in its centre.

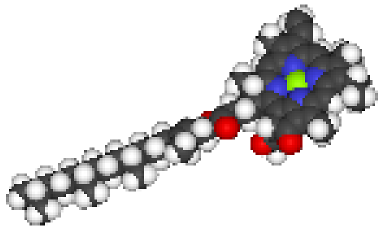


Figure 5: Chlorophyll-*a* molecule with a Mg^{2+} ion, indicated in green.

During the cooking process this magnesium ion can in acidic conditions be replaced by two H^+ ions to give a compound called phenophytin (6). This compound is responsible for the brown colour of cooked vegetables. There appears to be no good reason why addition of cooking salt or NaCl (s) would affect the colour of vegetables during cooking. This needs further inquiry. Some top cooks add sodium hydrogen carbonate to keep the cooking water alkaline. Alkaline conditions minimize the replacement of Mg^{2+} ions and therefore the change in colour. But alkaline conditions in cooking probably affect the amount of vitamin C. This as well needs further inquiry. Moreover, what would happen to the colour of cooked vegetables when other salt solutions like $CaCl_2$ (aq) are used?

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