Eszter Imola Tisza-Kosa[1], Andras S. Szabo[1], Gergely Levente Szabo[2], Margit Izsak[1], Janos Bozi[1]

Received: 2016. June – Accepted: 2016. September

Teaching of natural sciences in schools with the help of food investigation experiments

Keywords: teaching of natural sciences in schools, analysis, food biology, food chemistry, food physics, measurement technique

1. Summary

Experiments are of primary importance in the teaching of scienctific knowledge. In our experience, it is a welcome sight for students if the subjects of the experiments are substances well known to them, in this case, different foodstuffs. Once again, 10 simple experiments of physical, chemical and biological character are described in the following topics: color development and pH value, masking of taste recognition, reaction of egg whites with salt and lemon juice, identification of glucose and sucrose, preparation of effervescent powder, determination of the fat content of milk, xanthoproteic reaction, wavelength-determination with cheese in a microwave oven, cooking in a pressure cooker (Kukta pot), detection of carotenoids.Foodstuffs used in the measurements and experiments are: carrots, cheese, citric acid, egg whites, glucose, lemon juice, milk, powdered sugar , raspberry syrup, red beet juice, red wine, sodium bicarbonate, table salt, tartaric acid.

2. Introduction

In the previous articles **[1], [2], [3]** information was given about the dominant role of experiments in the teaching of subjects of natural science. Hopefully, education will be more successful and effective if the teaching programs for natural science contain experiments as well.

Our former papers dealt with 10 experiments each, belonging to the physical, chemical or biological type. Of course, there are no sharp boundaries between these fields, and presenting the connections is an important part of the modern method of education in the natural sciences. This paper provides information again about 10 simple experiments, covering the field of food investigations. The measurements can be carried out without problems in normal shool labs, suitable for physical, biological and chemical investigations.

3. Descriptions of the proposed experiments of natural science

3.1. Why is red beet red, and does its color change as a function of the pH value?

It is written in the chemistry book **[4]** for 9th grade students, that it was stated by Boyle in the 17th century, that acids are those compounds, which change the color of plant extracts to red. An interesting phenomenon is also mentioned in the book: the color of the flowers of the ornamental shrub, garden morning glory (*Ipomoea purpurea*) depends on the time of day it is observed. In the morning, the color is dark blue and then during the day, due to the photosynthetic activity (physiological processes of assimilation change the pH of vegetable saps, and they gradually become acidic), the color changes to red.

The colored substances, giving red beet its characteristic color, belong to the group of anthocyanins (anthocyanidins). We investigated whether the color

[1] Ward Mária Elementary School, High School and Music Vocational School of Budapest
[2] Budapest Technical Vocational Center, Lajos Petrik Bilingual Chemical, Environmental and Information Technology Vocational School

of red beet juice changes if the pH is modified, by adding an acid (citric acid) or an alkaline substance (sodium bicarbonate) to the juice. In the case of red beet, there was no significant change in the color, the addition of citric acid produced a slightly more intensive red color, and the change in pH to the alkaline range did not modify fundamentally the original red color of the juice either. The conclusion: not (or not only) anthocyanin compounds are responsible for the red color of red beet juice. The reason: anthocyanins are present in the oxonium form in acidic media, but as a result of an increase in pH (alkalinization), a quinoidal structure is gradually formed, and the color changes step by step from red to a bluish tint **[5], [6]**. This is the same transformation that happens in case of the indicator known as litmus.

Let us mention, that the experiment was carried out with red wine as well. We found that acidification did not affect the color here either, however, alkalization affected the color significantly, the original color gradually developed a brownish-blueish tint.

3.2. Masking of aroma materials in raspberry syrup

It was proven in many earlier experiments **[7], [8], [9], [10], [11], [12], [13], [14]** that the perceptibility and recognition of taste intensity of flavor components in a system (in this case, foodstuffs) depnds on the presence of other components as well. In the experiment, students tested the sweet taste of raspberry syrup in a 1:5 mixture, diluted with water. There were two samples, however, one sample was supplemented with 1% citric acid. The task was to recognize the sweeter sample: they had to write down which one they felt sweeter and whether they perceived any difference between the sweet flavors. The students had the possibility of tasting the samples again.

The typical flavoring substance in raspberry syrup is 4-(4-hydroxyphenyl)butanone, although it contains other flavoring agents as well - predominantly sugars and organic acids - and these components produce the sweet and sour taste. More than 80% of the students marked the sample, supplemented with citric acid, less sweet, while some of them could not distinguish between the two samples. Nobody felt the sample supplemented with citric acid sweeter. Thus, it can be concluded that the presence of citric acid in significant concentrations reduces the intensity of the sweet taste. Obviously, because in the perception process (stimulus-nerve stimulation-sense) the signal of the biosensor, detecting the presence of sweet flavoring substances is interfered with by the signal of biosensor, detecting the sour taste. In practice, for example, a similar incident occurs when consuming cherry and sour cherry fruits with approximately the same sugar concentrations, but cherries seem sweeter. It feels so because of the different acidities, the acidity of sour cherries (due primarily to malic acid, citric acid, succinic acid and ascorbic acid) is significantly higher than the value that can be measured in cherries **[15].**

3.3. Reaction of egg whites with table salt and lemon juice

In the experiment carried out with NaCl, egg whites were put in a test tube together with table salt and then, after some time, distilled water was added. Experimental evidence indicated that, when adding a small amount of salt, there was no change in the protein, however in the case of larger amounts, the protein precipitated, but could be redissolved by the addition of water. This phenomenon can be explained by the fact that the hydrate shell (water) of the protein molecules is removed by the hydration of the ions , therefore, the protein molecules are conjugated. However, when adding water, a hydrate shell forms again (the change is reversible). In the experiment carried out with lemon juice, the protein precipitated on the wall of the test tube and, in spite of the added distilled water, the protein did not dissolve. The explanation is that when acid is added to the egg protein, the structure of the proteins (called albumin in egg whites) is chemically changed. Thus, because of the influence of the acid, the protein is denatured and precipitates on the wall of the test tube, so the change is irreversible.

3.4. Identification of glusose and powdered sugar solutions

The task is to distinguish between and to identify glucose and sucrose solutions, using, e.g., Tollens' reagent, producing in the reaction a silver mirror. First, the reagent is prepared for the experiments, by putting in a test tube silver nitrate solution, and then adding ammonia solution until the precipitate, which forms initially, is dissolved. This reagent is added to the glucose and sucrose solutions. Test tubes are heated (using a gas burner or ethyl alcohol burner) and the changes are observed. It can be observed that, during the silver mirror test, in the test tube containing the glucose solution, metallic silver (a silver mirror) is precipitated. However, there is no change in the test tube containing the sucrose solution. This phenomenon can be explained by the fact that since glucose is a reducing monosaccharide, and the glucose molecules include formyl groups, glucose presents the typical reactions of aldehydes, such as silver mirror test as well. Sucrose is not a reducing disaccharide, the two rings that form its molecules do not open even in an aqueous solution, so formyl groups (CHO) cannot form either. Therefore, the sucrose solution does not produce a positive silver mirror test. The general equation of the silver mirror test:

$$\text{R-COH} + 2\,Ag^{+} + 2\,OH^{-} \rightarrow \text{R-COOH} + 2\,\underline{Ag} + H_2O$$

Note that, when solutions of the same concentration (e.g., 2%) of both carbohydrates are prepared, the difference between them can also be detected organoleptically. This is so because the sweetness of glucose is substantially less intensive, than that of sucrose. So, in this case, the analytical task can also be accomplished by applying the easiest and most natural measurement technique, the use of human biosensors.

3.5. Preparation of effervescent powder (and a soft drink from the powder)

Acid-base reactions are of great significance in the food chemistry as well. The dissolution of various effervescent tablets also starts with acid-base reactions. Dissolution is accompanied by gas evolution. Powders, similar to those used in effervescent tablets can be created easily in the chemistry lab, thus illustrating the operating principle of the real tablets and its chemical background.

For effervescent powder preparation - for demonstration purposes – use approximately 1 g of tartaric acid, 1 g of sodium bicarbonate (baking soda), and, additionally, for beverage production, about 10 g of granulated sugar and 100 cm^3 of water is needed **[16]**. Tartaric acid and sodium bicarbonate were first pulverized in a mortar, then the mixture was poured into a beaker and water was added. As a result, vigorous effervescence is observed. When the sugar is dissolved in the beaker, a beverage with a pleasant taste is obtained.

The explanation of the violent effervescence of the effervescent powder during the dissolution is that the tartaric acid as a weak acid and sodium bicarbonate as a weak base react in an acid-base reaction with each other, whereby CO_2 gas is formed according to the following reaction:

The advantage of the experiment is that the required materials are readily available, and so the experiment may be carried out even at home by the students. It should be noted that even though in a chemistry lab, in principle, the consumption of food and drink is prohibited, provided that the hygiene conditions allow it, the explanation of the experiment can be carried out in the form of a common beverage consumption as well.

The experiment also provides a good opportunity to look back at the characteristics and differences of chemical and physical dissolution. However, this experiment can be used not only in the teaching material of the 9th grade, but also for the 10th grade, when discussing organic acids. In the latter case it is worth mentioning that tartaric acid is one of the very important representatives of organic acids in wine, while, as an acidity regulator and antioxidant, it is widely used in the food industry as well.

3.6. Comparative measurements of the fat content of milk samples

The fat content of commercially available cow's milk is mostly between 1.5 and 2.8%, although milk with a fat content in the range of 0.1 to 3.6% can occur. However, the fat content of fresh milk from a cow is significantly higher, usually around 4%. Although the composition of milk produced by dairy cows considered to be fairly stable, the fat content of fresh milk is slightly affected by many factors, e.g., the breed of cattle, the season, the composition of the feed, and it can also change during the milking. To compare the fat content of milk samples with different fat content – we worked with industrial milk samples, containing 1.5 and 2.8% fat – we need ether (or petrol ether), 50 cm^3 graduated cylinders (corresponding to the number of samples), a 200 cm^3 separating funnel and Petri dishes, and, additionally, a water bath and a scale is required **[16]**. In essence, the measurement is a gravimetric method, combined with extraction.

For the investigation of the fat content of the samples, 50 cm^3 of each milk sample was poured into a separatory funnel, 15 cm^3 of diethyl-ether was added, and the mixtures were shaken vigorously for several minutes. After separating the aqueous (bottom) phase and the organic (upper) phase, 8-8 cm^3 of the ether solution was poured into each Petri dish of known weight, and it was concentrated on a water bath. The fat content of the samples is calculated from the mass of the residues after evaporation. Interestingly, it may be noted that, in the common language, there are also other beverages called "milk" (eg., rice milk, soy -milk, coconut milk), which should not be confused with genuine milk of animal origin. However, it is an interesting fact that, for example, coconut milk has an extremely high fat content, up to 17%. In addition to milk, it is worth mentioning the fat content of different dairy products. Perhaps even more effective is to make the students look at the composition of condensed milk, yogurt, kefir, cream, butter, cheese and curd products, found on the shelves of food stores.

3.7. Detecting proteins using the xanthoproteic reaction

Pour into a test tube about 2 ml of milk and 1 ml of concentrated nitric acid. Warm the mixture gently, but do not boil it! Be very careful because of the very corrosive effect of concentrated acid, especially during heating! As a result, a yellow color reaction can be observed.

The essence of the explanation is that with the xanthoproteic reaction those proteins (polypeptides) can be detected, which contain benzene type amino acids. As an effect of concentrated nitric acid, the benzene rings of these amino acids (phenylalanine, tryptophan, tyrosine) are nitrated, and thereby converted into characteristic nitro compounds. The word "xanthos" is a greek word, meaning yellow, the word protein refers to the protein albumin, hence the name of the reaction. Since these amino acids with an aromatic ring are found im almost all proteins, this reaction for detection is a typical, commonly used method for proteins.

3.8. Microwave melted cheese

Today, almost every household has a microwave oven, about the application of which we have already written in our previous paper **[3]** as well. The present experiment is designed to understand the work of the oven better, that is, what type of waves are microwaves. We should clarify for the students, that "micro" is a greek word, which in english means "small". Of course, not to be confused with the "micro" prefix, which has a specific mathematical content when placed in front of, e.g., a unit of length: 10 to the –6th power. However, microwaves do not have micrometer (10^{-6} m) wavelengths.

For the experiment, there is a need to take out the rotating plate of the microwave oven and replace it with a piece of cardboard of such size that covers the bottom of the oven. The piece of cardboard is covered with grated cheese or a thin layer of cheese, evenly dispersed on the cardboard **[18]**. Next, turn on the oven for about 30 seconds. The cheese melts in certain areas (swelling places), while elsewhere it remains cold (these are the nodes, the nodal places of the waves). Explain to the students that, as a result of the electrical power, stationary waves have been generated in the oven. We can conclude that the distance between the melted parts of the cheese represents the wavelength of the stationary microwaves. Experience shows that the distance between the molten parts is approximately 6 cm, and this is half of the total wavelength. Thus, the microwave oven works with about 12 cm wavelength waves. If we substitute this into the equation then is obtained, meaning that the frequency of the electromagnetic waves is 2.5 GHz. In reality, these are 2.45 GHz waves, and so this simple measurement gives a very good estimation for their frequency.

3.9 Cooking in a pressure cooker (kukta pot)

The use of a pressure cooker for cooking and stewing food has several advantages, such as faster and more energy-efficient preparation of a meal. But what happens in the pressure cooker, looking at the process from a physics point of view?

We start cooking the food with a certain amount of liquid (here, water) in the pot, and close the cover of the pressure cooker. In the closed vessel, the pressure of the vapor, generated over the liquid as a result of the heat treatment, is well above atmospheric pressure (approximately 10^5 Pa, i.e., 1 bar). Under such circumstances, the boiling point of water will be higher. That is to say at the temperature, where, at atmospheric pressure, the water would begin to boil, the water in the pressure cooker pot still does not start to boil. It should be explained to the students that boiling occurs when the external pressure (here, in a pressure cooker, the pressure in the closed space) is equal to the saturated vapor pressure of the liquid. I.e., the higher pressure above the liquid does not allow the generated vapor bubbles to escape, and therefore boiling does not start. It should be noted that due to the interaction between the food to be prepared in the pressure cooker and the water, certain substances (e.g., salts, sugars) are dissolved from the raw food material and thereby a solution with a specific composition is formed, which itself has a higher boiling point than that of pure water.

In particular, even from a kitchen technique point of view, it is advantageous to use a pressure cooker, since by using only a small amount of water the foods to be prepared are stewed and not cooked, thereby preserving more of the vitamin and mineral content. Of course, with a valve on the pressure cooker lid, the pressure can be controlled, as it would be dangerous to use a completely sealed pressure cooker for cooking.

Still, we should work with caution when the food is removed from the heat. Either the pressure cooker should be left to cool by itself, or we can help with cold water cooling. It is an interesting phenomenon that when the lid is removed, the meal can start to boil in the pressure cooker, because the temperature can still be higher than the boiling point corresponding to the lower pressure.

3.10. Identification of carotenoids

Carotenoids are lipids, found both in plant and animal organisms. The π-electrons of the conjugated double bonds found in carotenoids are delocalized, so photons of visible light are capable of exciting them. The spectra of the reflected, absorbed or emitted light energy are such, that the molecules are colorful, and the color ranges from yellow to red.

Carotenoids include lycopene, the substance responsible for the red color of tomatoes, carotene, providing the orange color of the root of carrots or the fruit of pumpkin, and also the yellow xanthophylls, playing an important role in plant photosynthesis together with carotene. The fat-soluble vitamin, vitamin A, which is important for animals and the human body in skin protection and healthy vision is also a carotene derivative, belonging to the group of carotenoids.

During the test, it is very important to use clean and dry equipment, because even a minimal amount of moisture can interfere with the reaction. For the tests, a vitamin A preparation and carrots were used, and the detection of carotenoids was carried out from these substances.

For the first measurement, 2-3 drops of the oily vitamin A preparation is placed in a dry test tube, to which 1 ml of chloroform is added and shaken well. A few drops of the solution obtained are spotted in the middle of a filter paper, always waiting until the previous droplet dries. When the stain is dry, 2 drops of antimony trichloride, dissolved in chloroform are

SCIENCE

TEACHING OF NATURAL SCIENCES WITH THE HELP OF FOOD INVESTIGATION EXPERIMENTS

added. Vitamin A provides a blue color reaction. In the second measurement, 2-3 g of grated carrots are mixed with about 5 ml of an alcoholic potassium hydroxide solution, and it is triturated well in a mortar. After a few minutes, pour the liquid into a small separating funnel, adding the same amount of chloroform to it. The mixture is shaken thoroughly, and the lower chloroform layer is drained into a dry test tube. The material of the test tube is shaken with small amount of anhydrous sodium sulfate until the solution becomes clear. A few drops of this solution are spotted on a filter paper with a dropper, always in the same place. Then on the dried stain two drops of antimony trichloride, dissolved in chloroform, are spotted. The carotene content of the carrots also gives a blue color reaction.

The explanation for the color reaction is that antimony ions chmically bind to the carotenoid molecules, thereby changing the light absorption of the delocalized π-electron system, and this change causes the appearance of the blue color.

4. Conclusions

We believe that the described 10 simple experiments of physical, chemical and biological nature, based on the investigation of foodstuffs and the study of the phenomena using foodstuffs, and the presentation of these experiments in the class helps students to prepare for natural science subjects. In addition, the discussion of the measurement data, interpretation, and of course the drawing of conclusions will improve their logical skills as well. And the fact that the experiments were performed with agricultural products and foodstuffs well-known to students in everyday life, strengthens our hope that useful information was given to students also about food and nutrition, arousing their interest in the food sector.

5. References

[1] A.S. Szabo, M. Izsak, J. Bozi: Teaching of chemistry and physics in elementary and high schools with help of food science experiments. J. Food Investigation, 61(2), 647-656, 2015.

[2] J. Bozi, A.S. Szabo, M. Izsak, E. Tisza-Kosa, G.L.Szabo: Teaching chemistry, biology and physics with the help of food analytical experiments. J. Food Investigation, 62(1), 990-995, 2016.

[3] M. Izsak, J. Bozi, E.I. Tisza-Kosa, G.L. Szabo, A. S. Szabo: Education of natural science in schools with help of experiments of food investigations. J. Food Investigation, 62(3), 1184-1189, 2016.

[4] E. Sipos-Kedves, B. Horvath, L. Pentek: Chemistry textbook. General and inorganic chemistry, Class 9, Mosaic Publ. House, Szeged, 2013.

[5] K. Gasztonyi K., R. Lasztity (eds.) : Food chemistry. Mezőgazda Publ. House, Budapest, 1992.

[6] H.D. Belitz, W. Grosch, P. Schieberle: Food chemistry. Springer Verlag, Berlin, 2004.

[7] A.S. Szabo: Invesgtigation of complex taste recognition ability, comparative sensory mesurements of interactions of basic tastes. I.-II.-III.-IV.-V.-VI.-VII.-VIII, Food Industry, 41(4), 138-140, 41(5), 181-182, 1987, 45(3), 101-103, 1991, 60(4), 119-121, 2006, 61(4), 125-127, 2007, 63(3), 88-90, 63(4), 119-120, 63(5), 154-155, 2009.

[8] A.S. Szabo: Investigation of interaction of basic tastes by organoleptic evaluation of foodstuffs. 9th World Congress of Food Science and Technology, 30.07-04.08. 1995, Budapest, book of abstracts, Vol. 1., p. 100.

[9] A.S. Szabo: Investigation of perceptibility of sweet taste in the presence of other aroma components. Study of interaction of basic tastes. Int. Symp. on Sweeteners, Jerusalem, Israel, 14-20 July, 1995, book of abstracts, p. 31.

[10] A.S. Szabo: Investigation of perceptibility of sweet taste in the presence of other aroma componenst, study of interaction of basic tastes. Publ. Univ. Hort. Ind. Aliment., 57, 23-27, 1998.

[11] A. S. Szabo: Investigation of interaction in perceptibility of sweet and bitter taste. IUPAC-ISS, 13-17 Nov., 2001, Hiroshima, Japan, Conf. book of abstracts, p. 57.

[12] A.S. Szabo: Investigations for study of interaction in perceptibility of sweet and bitter tastes by sensory evaluation. J. Food Phys., XVII-XVIII, 77-84, 2004/2005.

[13] A.S. Szabo: Investigation of the ability of taste-recognition for salty taste (sodium-chloride) in presence of citric acid. J. Food Investigations, 64(3), 173-179, 2008.

[14] A.S. Szabo, M. Csoka M.: Investigation of the abilities of taste-recognition and recognition of the difference in taste-intensity for students. Food Industry, 59(6-7), 189-191, 2005.

[15] I. Rodler (ed.): Propositions for Nutrition, Dietary Guidelines, nutrient data in tables. Budapest, National Public Health Programme, National Institute of Food and Nutrition, 2004.

[16] M. Rozsahegyi, J. Wajand J.: 575 experiments for chemistry teaching. p. 545., National Textbook Publisher, Budapest, 1991.

[17] M. Rozsahegyi, J. Wajand J.: 575 experiments for chemistry teaching. p. 553., National Textbook Publisher, Budapest, 1991.

[18] Cs. Degen, F. Elblinger, P. Simon: PHYSICS 11. Educational Research and Development Institute, Budapest, 2015.