Food Science Short Notes

A Summary of the Nuffield Students Booklet

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1 Introducing Food Science

1.1 Science of Food

A decreasing percentage of the population in Britain is involved in food production.
Science and technology in developed countries have helped increase food production and give a broader variety of foods at lower prices.
Food science looks at what food is chemically, the causes of food spoilage, and the processing and preservation of food.

1.2 Public Concerns

Issues in the public eye include dieting, cholesterol, salt content, and organic and GM foods.

1.3 Nature and Content of Food

Nutrients provide chemicals for tissue growth and repair, maintain body structure and provide energy for activity.

- Energy: Carbohydrates, Fats, Proteins.
- Growth & Repair: Fats, Proteins, Minerals.
- Controlling Process: Proteins, Minerals, Water, Vitamins.

A substance is only food if it provides one or more of the above nutrients *and* it is eaten in quantities that make a significant contribution to daily nutritional uptake *and* it is culturally accepted as being food.
For the reasons above pepper, tea, coffee, dogs, and snakes are ruled out.
Oxygen is also needed continuously by the body for respiration (oxidation of food) which gives energy for all processes and heats the body and the surroundings.
The energy of basal metabolism is the energy requied to maintain vital bodily functions (roughly 6700 KJ/day).

1.4 What is in the Food we eat?

14% of energy from meat, 12% from bread, 22% from cereal, 35% from fats.
61% of protein comes from meat.
Vitamin C comes mainly from fruits but 18% from potatoes.
Vegetables also provide dietary fibre (indigestible cellulose) which has a water binding capacity to add bulk to the faeces.

2 Nutrients in Food

2.1 Fats

Esters of glycerol; properties depend on the fatty acids and degree of saturation.
Unsaturated fats are liquids, saturated fats are more viscous and solid at room temperature.
Fats provide:

- A concentrated energy source
- Essential fatty acids (all unsaturated, e.g. linoleic, linolenic, arachidonic)
- A solvent for vitamins A, D, E and K.
- Thermal insulation and physical protection.

Main sources are butter, margarine, meat and milk.
Unsaturated fats are hardened and made more stable by reduction of their unsaturated fatty acids using hydrogen gas and a Ni catalyst at 180°C.
The degree of saturation of a fat is measured using Wij's solution (Iodine monochloride). It reacts with the double bonds in the chains so the degree of unsaturation is the amount of iodine absorbed (grams of I_2 to saturate 100g of fat).

2.2 Proteins

Primary structure is the sequence of amino acids, secondary can be an alpha-helix spring shape, and tertiary is the folds of the secondary using H and ionic (NH_3^+/CO_2^-) bonds.
Fibrous: Inelastic chains (fibrin) are held in extended helices by cross links. Elastic chains (keratin, myosin, and elastin) are unextended and held by hydrogen bonds.
Globular proteins (albumen, casein, gelatin) are twisted into a ball shape.
Fibrous are insoluble, resistant to some pH and temp changes. Globular are the opposite.
Proteins have structural roles (collagen, albumen, haemoglobin) and can be buffers.
Enzymes are made of proteins, which specifically control biochemical reactions. They are very sensitive to pH and temperature change (plants: 5°C, animals: 37°C) since they denature at high temperatures (hydrogen bonds break).
Digested proteins are hydrolysed to amino acids. 8/21 amino acids are essential.
Animal protein contains all essential amino acids, vegetable protein lacks some.

2.3 Carbohydrates

Plants (e.g. cereals, root plants) are the main course of dietary carbohydrate.
Simple monosaccharides reacr by condensation to form disaccharides.
Polysaccharides are polymers made of monosaccharides (often glucose).
Starch contains two polymers of glucose. Linear amylose and branched amylopectin.
Cellulose cannot be digested by humans but provides roughage.

2.4 Vitamins

Needed in small quantities in a healthy diet
Vitamin C is a good reducing agent. Deficiencies are common since it is soluble (washed out of food) and thermally unstable (destroyed in cooking)

2.5 Minerals

Elements form part of the body structure (Ca, Mg, P for bones/teeth), help osmotically and for buffers, and form parts of enzymes.
See the Nuffield book for tables of vitamins and minerals to learn.

2.6 Water

Needs replacing (some by food) since it is continually lost as sweat and urine. Needed for transport of nutrients, rigidity in plants, and chemical reactions.

3 The Quality of Food

3.1 Eating Qualities

Food must have desirable eating qualities if it is to be eaten
These are divided to structural (water holding capacity, texture, tenderness, juiciness) and chemical (taste, odour, colour).
Membranes of cells are made out of lipids and proteins in phospholipids. The hydrophobic tails form a bilayer with the hydrophilic heads at each side.
The membranes are selectively permeable. Big molecules can't get through.

3.2 Water Holding Capacity

This dictates some of the texture, tenderness, and juiciness.
Water is held H bonded to polar groups, by hydration of free ions or Mg/Ca in proteins and most of all ”free” but trapped within protein or polysaccharide meshes (by ionic/H bonds) called gels
pH and temperature affects these gels by affecting the bonding and water is lost.
The firm feel that strawberries have comes from juice being released from cells as you bite into it. This is not seen with frozen ones where most of the water is in intercellular spaces

3.3 Texture in Plants

The firmness of plant tissue comes from:

- water (that moves in by osmosis since there is much solute in the cells) pressing on the cell wall.
- the strength of cell walls.
- the efficiency by which the cell walls are cemented together.

Fruit and vegetables have a high percentage of water making them firm and crisp rather than limp and spongy. This softening is due to the degradation of cell walls.
Cell walls are 90% carbohydrate and the rest is protein.
Cell wall strength comes from the hemicelluloses (short polysaccharides) which can hydrate to a gel to hold the cellulose myofibrils.
There are also pectins in the wall which are mainly galacturonic acid. It contains COO_2^- groups which bind with calcium which gives calcium pectates (bind adjacent cells together).
Middle lamella is rich in pectins, which degrade upon ripening which softens the tissue by lowering cell to cell adhesion.
Galacturonic acid can be a free acid or a methyl ester. It is the size of the pectin chain and the amount of methyl esters that determine the gelling properties.
Pectins form gels for jam and ketchup.
In vegetable cooking pectin becomes soluble and gives mushy vegetables (add Ca to stop this).
The degradation of pectin in ripening is by polygalacturonase, it converts pectin into short chains.

3.4 Texture in Animals

Skeletal muscle is made of fibres which give the texture.
Connective tissue os made of the proteins collagen and elastin which contribute a rubbery texture. When cooked they form gelatin (a desirable texture).
Collagen is more cross-linked in old animals giving tougher (less desirable) meat.
Myofibrils make up meat. A sarcomere is the repeated unit of dark/light bands. The dark bands are thick myosin and the light are thin actin.
Myosin slides between actin in contraction, shortening the sarcomere. Held by titin.
After death the sarcomeres shorten and the actin and myosin become welded together (RM) until the meat ages (calpain used) or papain is added which restores the water holding capacity of the meat.
The texture of the meat is also influenced by fat. Consumers request low fat but a small amount (marbling) is good for cooking and flavour release.
Meat is a very concentrated source of nutrients.

3.5 Flavour and Colour

Four flavours: bitterness (back of tongue, quinine, caffeine), acidity (aka sour, second from back, citric fruits), salt (third from back), and sweetness (front of tongue, sugar, saccharin).
Monosodium glutamate enhances flavours.
Noses are very sensitive to odours. Odours are caused by many different compounds.
Colouring is by porphyruns (complexes e.g. haem, chloro), carotenoids (fat-soluble, yellow to red) and anthocyanins (yellow, red and blue). Carotenoids and anthocyanins and from fruit and vegetables.
Pigments are thermally unstable (e.g. cooking vegetables).
Discolouration can also happen by enzymic browning

3.6 Genetic Modification

Genetic engineering aims to add genes to change behavious , inactivate a gene to remove unwanted behaviour, or to modify a gene to give higher yields.
One example is GM tomatoes which have less polygalacturonase so they last longer.
GM is also used to produce ingredients like Vitamin C, aspartame, and caffeine free coffee.
In cheese making microbes are used as the source of the enzyme chymosin.

4 Microbial and Biochemical Changes in Food

4.1 Types of Change

Change can be due to microbes, biochemical reactions or cooking and processing.
Change can be beneficial (making cheese) or undesirable.
Food must be storable since agricultural production is seasonal and demands from consumers are fairly constant throughout the year.
Storage life is the time at 10 - 15°C in dry conditions for significant deterioration to occur.

4.2 Microbial Changes

Moulds are the most common and are microscopic fungi (a network of filaments).
Rapid growth in humid conditions. Generally undesirable (bar blue cheese).
Yeast are 7000 nm, also fungi, oval shaped and used to ferment sugars for alcoholic drinks are breadmaking.
Bacteria are smaller (2000 nm), have two shapes: cocci (spherical), bacilli (rod).
Spoilage organisms make food unpalatable but are not a danger to health (souring by lactobacillus is an example).
Pathogens cause disease. Some via toxins in the food (SA, CB), others by growing in the body (Salmonella, LM).
Microbes reproduce by cell division. In the lag phase they adapt to new conditions, then they grow in the exponential phase until the stationary phase where nutrients are all used up/toxins produced/pH change.
Food becomes unpalatable before the stationary phase is reached.
Psychrophilic grow best 10 - 15°C, mesophilic 20 - 40°C, thermophilic 55 - 65°C.
Bacteria need 20 - 40% moisture, yeast and mould need less.
Bacteria grow best in alkaline conditions, yeast neutral, mould acidic.

4.3 Microorganisms & Food Poisoning

A food borne disease is caused either by the presence of harmful bacteria or toxins.
Salmonella gives gastroenteritis. They release toxins in the small intestine leading to fluid loss and diarrhoea. Heat kills it. Found in meat, poultry and eggs.
Campylobacter jejuni is like Salmonella. Gives cramps are diarrhoea. From chicken.
Listeria monocytogenes only affect the young, the old, and the pregnant. Can give meningitis (or listeriosis). Heat kills it. From soft cheese, raw meat, and milk.
Staphylococcus aureus carries in the skin and nose. Gives a toxin that is heat stable and

gives vomiting and diarrhoea. From cold food in warm room after handling.
Clostridium botulinum reverts to spores in hostile conditions. The toxin is not heat stable but is very toxic, 50% of people die. From canned foods.
Escherichia coli carried in human faeces. Give diarrhoea. From not washing hands.
To be safe food should be stored so that microbes can not grow. Refrigeration only delays growth. Spores can survive cooking. Eat food quickly after short high temperature cooking.

4.4 Microbial Changes in Milk

Milk is ideal for microbes, it has many nutrients. Many from soil and water.
Souring involves the conversion of lactose to lactic acid lowering the milk's pH. This breaks the bonds casein has with Ca and P making it less soluble so it coagulates to curd. The other proteins in milk (globulins, albumins) are left as whey.
But the curd is good for storage (it is stable) and the process is used in making yoghurts with added bacteria to control the taste and flavour.
Pasteurised (mild heat treatment) milk spoils by protein and fat breakdown.
Proteolysis forms amino acids from proteins and then NH_3, H_2S, CO_2 etc.
Lipolysis forms fatty acids from fats the aldehydes etc. (rancid taste and smell)
Beneficial changes in milk include making cheese. First you encourage the production of acids (use lactic acid producing bacteria). Then add rennet to make the casein less soluble forming a soft curd. Then heat to destroy the microbes and allow cheese to mature. The flavour depends on the microbes (and other things).

4.5 Non Microbial Changes

Pectin breaks down in fruits and vegetables in ripening. In growth insoluble protopectin forms and during ripening this degrades into more soluble compounds. This makes fruit mushy.
A desirable change is that of meat from living muscle to hung meat. The flavour increases as it tenderises (changes in enzymes without oxygen).

4.6 Browning Reactions in Fruit & Vegetables

Benzene-1,2-diol was required for the browning (it is the substrate found in the potato). Crushed apple works quickest. Even quicker if you break the surface. Caused by an enzyme within the apple.
Phenol can be used to kill microbes. As no difference is seen with the phenol used it indicates that it is not due to microbes. Instead it is a biochemical change.

An enzyme related reaction should be temperature dependent, and it is.
It is an enzyme based reaction requiring oxygen (determined through exposure to different gases).
Ascorbic acid can be used to delay browning (it is an antioxidant - it is oxidised instead), acids can inactivate the enzyme by lowering the pH, boiling denatures the enzyme, sugar slows it down by reducing oxygen solubility in the tissue, salt and SO_2 both inhibit the enzyme.

4.7 Changing Milk with Enzymes

Using rennet to make cheese is the slowest way, chymosin is faster and a microbial protease fungus is faster still.
Acidification causes bonds between casein and Ca and P to break which decreases its solubility. It coagulates and separates in what has already been described: curdling.

5 Food Preservation

5.1 Methods of Preservation

Raw food is unstable it spoils by microbes, biochemical reactions & physical damage.
Food preservation reduces deterioration and increases shelf life by inactivating enzymes and microbes (heat, irradiation, chemicals pressure) and creating conditions in which deterioration is limited (freezing, dehydration, packaging).
Methods must keep food acceptable. The nutritional value should not be affected and the resulting food should not be harmful.

5.2 Methods which Destroy or Inactivate Microbes and Enzymes

Heat treatment is either by sterilisation (kill them all) or pasteurisation (leave some spoilage organisms).
Vegetables should be blanched first using hot water or steam to inactivate enzymes.
In pack sterilisation creates a vacuum by replacing air with steam which condenses. It is then heated and cooled with sterile water. Nutrient value reduced, and needs long time (as heat takes a long time to penetrate).
Ultra high temperature treatment (UHT) passed liquid foods through heat exchangers at 140°C for 5 seconds. It is expensive.
Pasteurisation uses a high temperature short time (HTST) process for milk. E.g. 94°C for 0.1 seconds to avoid cooked flavours.

Products with pHs greater than 4.5 support many microbes. 100°C for 5 hours.
Between pHs 3.7 and 4.5 you only need a ST. Less than 3.7 VST is needed for enzymes only.
Irradiation by gamma or high energy electrons can be used. It stops deterioration processes and destroys microbes. But consumers resist this and it damages food.
High pressure (1000 - 10000 atm) can be used to kill microbes and change enzymes.
Acid can be added to reduce the pH to inhibit microbes and enzymes. E.g. lactobacilli in milk make acid, or adding ethanoic acid to vegetables (pickling after soak in salt).
Salt can be used for the curing of meat. Soak the meat in 25% NaCl, some $NaNO_3$ and some KNO_3 (inhibit spoilage). Leave it for 12 days. Alternative: inject into meat.
Smoking afterwards for 20 hours coats in condensed tar inhibiting microbes.
Antibiotics are produced by and inhibit microbes. Often not permitted due ti the resistance issue. Nisin is allowed, and is added to cheese to stop spores.
Antioxidants prevent the oxidation of unsaturated fatty acids to aldehydes in processed foods.
They are added to oils, fats and butter. Vitamins C and E and both examples. Synergists (Vitamin C) form complexes with Cu to stop it being catalyst for the oxidation.

5.3 Methods which Create Conditions that Limit Deterioration

Freezing reduces the rate of growth and slows enzymes. Since H_2O freezes, the microbes can not further deteriorate the food. 5°C ST, -18°C for long (but not forever).
The rate of freezing is vital. Generally little nutrient loss (more lost in preparation).
Fast freezing destroys up to 80% of microbes. Little damage, small crystals.
Slow freezing may destroy more but large crystals mean dehydration making the food mushy.
Blast freezing uses air at -30 or -40°C. Fast uniform freezing.
Immersion freezing uses cold solutions of salt and glycerol. Use N_2 (l) in cryogenic. This is expensive.
Plate freezing (by contact) uses hollow plate with refrigerant. -40°C used. Only for flat thin items.
Dehydration removes 90% of H_2O. Sun drying is popular. Heat drying is from 40 to 100°C. Some cell damage occurs and less H_2O is reabsorbed. Freeze drying freezes and removes water by sublimation.
Damage is possible as the food becomes fragile. Nutritional content falls but rehydration is easy.
Packaging protects against handling, dehydration, moisture uptake and fat oxidation.
A modified atmosphere of 75% O_2 and 25% CO_2 is good for keeping colours but inhibiting microbes.

6 Cereal Science

6.1 Wheat Grain

Wheat grain contains cellulose, starch, protein, some fat, vitamins and minerals.
6 by 3 mm with a beard at one end, a crease down the side, and a tough skin (bran) featuring an aleurone (single layer, fat and protein) and pericap (brown, cellulose) layer.
Main part of the grain is the starchy (some proteins too) endosperm coated by the aleurone.

6.2 Moisture Content

This is key since it determines the price. More water means less protein, so cheaper.
At 18% it will germinate at 18°C. 10 - 15% is good. Milling 15 - 16% for separation.
Moisture content is determined by the climate upon harvest. Aim for under 18%. It is numerically the loss in mass as a percentage of a 10g sample heated at 130°C for 2 hours.

6.3 Protein Content

Protein quality means characteristics of the gluten, which is the viscoelastic complex formed from proteins in the flour mixing with water.
Bread making requires 12 - 14% protein. Strong flour is more elastic. Gluten retains the gas bubbles as they form in baking. So cakes don't need strong flour.
Gluten is made up of insoluble gliadins and the even more insoluble glutenins. The more glutenins the stronger the dough you get when you add water.
The protein content is determined by the nitrogen content available when growing.

6.4 Starch

This is the largest component of wheat. It is made of alpha glucose.
Uncooked it is indigestible but upon heating digestive enzymes are enabled and H bonds are broken allowing H_2O to move in. Round ball formed in gelatinisation.

6.5 Processing Wheat to Make Flour

Before milling the wheat must be conditioned by adding H_2O and leaving for 24 hours to hit the 15% moisture level. Then you grist (blend) different wheats to give the required quality.
Milling aims to give the maximum volume of flour at a given colour. The whiteness is dependent on the endosperm's whiteness, the particle size and the bran content.
The conditioned and gristed wheat is passed through break rollers to open the wheat and

separate the bran, the endosperm, the flour and the bran/endosperm bits. Then sieve, and purify to separate by density. Moore rollers break those still combinded.
Pure endosperm to reduction rolls to make flour.
The bread making properties of the flour improve with age since autoxidation of polyunsaturated fats bleaches carotenoids (whitens flour) and when SH groups of gliadins are oxidised the viscoelastic properties of the bread are improved. This is done artificially with Cl_2.
Good dough is made through mixing and kneading to stretch glutenin into linear chains which form sheets around gas bubbles by temporarily breaking glutenin binding bonds and exchanging disulphide bridges.
This is controlled by flour improvers (vitamin C) which are activated when water is added.

6.6 Bread Making

Dough is made from flour and water. The flour contains amylases which hydrolyse starch. When dough is heated starch granules take in water, soluble starch leaks out as the grains swell and hydrogen bonds are broken.
With even more heat the granules rupture giving more free starch making the mixture much more viscous. Gelatinised starch is much more readily hydrolysed by humans, so it becomes digestible.
Unleavened bread is made by baking the simple flour and water mixture. It lacks the honeycomb structure (lightness) given by gas bubbles.
To aerate the dough fermentation is used with yeast converting the glucose to alcohol and CO_2. Gluten holds the CO_2 in.
The gas expansion, starch gelatinisation, and the gluten coagulation give a rigid loaf.
Salt can be added to strengthen the gluten, and control the rate of fermentation.
Fermentation is run for 1 hour at 25°C. Kneading then introduces CO_2. It is cooked for 40 mins at 120°C. Beyond 55°C the yeast are killed and fermentation stops.
The Chorleywood bread making process makes bread in the UK. It replaces fermentation with high speed mixing in a near vacuum to give the bubble structure. 1% less protein can be used.

6.7 Investigating Flour

The SDS sedimentation test assesses the gluten content of flour. Ground flour is shaken with Na Dodecyl SO_4 (detergent) to give a gluten sediment as the insoluble protein swells. The volume of this is measured after 30 mins.
Strong flour has more gluten so has more sediment.

Increased swelling of starch grains is seen at higher temperatures. Maize flour (corn) needs a higher temperature to gelatinise flour.
Plain flour is darker than strong since it has more bran contamination. Both are darker when damp due to the enzyme polyphenol oxidase. Vitamin C is a good reducing agent and will convert I_2 to $2I^-$ removing the classic blue/black colour for starch.
Added Iron(III) to flour is tested for with potassium thiocyanate. It goes deep red.

Credits

These notes are a shortened version of the information found with the Nuffield Food Science Students Book. The notes were created by Sam Davyson in the summer of 2006. The document itself is written in LaTeX. Thanks to the *Text Formatting with LaTeX* tutorial for much help with this, along with the *iPackage* installer and the *TeXshop*.

Alternative formats are available: http://sam.davyson.com/a2/chemistry/fssn