Paper No: 1

Paper Title: Food Chemistry

Module No: 28: Chemical and functional properties of minerals in food

In addition to the organic components like proteins, carbohydrates, fats and vitamins etc. our food also contains small amounts of inorganic species called mineral elements. These minerals play key functional roles in health and nutrition of humans. In the context of food and nutrition the minerals may be defined as the elements other than carbon, hydrogen, oxygen and nitrogen that are present in food. These are present in relatively low concentrations in the food. About 25 of the elements occurring naturally on the earth's crust are known to be essential to life and are present in living cells. Further, since our food is derived from living plants or animals, these elements are expected to be present in our food.

The mineral elements can be divided into two groups on the basis of their amounts in the body. The **major minerals** are found in bulk concentrations in the body while the microminerals or the **trace elements** are present in very small concentrations. In terms of their biological roles, the mineral elements are divided into **essential elements** having known biological roles **nonessential elements** with unknown functions, and **toxic elements**. Sodium, potassium, phosphorous, iron, calcium, zinc, selenium, magnesium, copper, tin, cobalt, manganese and fluorine etc. are the examples of essential elements. These function as electrolytes, as enzyme constituents and as building materials in bones and teeth. Boron, aluminium, mercury, lead and cadmium are non essential elements. Of these boron and aluminium are non-nutritive and non-toxic whereas the rest are and non- nutritive, toxic elements.

Chemical and Functional Properties of Minerals in Foods

Even though minerals are present in foods at relatively low concentrations, they often have profound effects on physical and chemical properties of foods because of interactions with other food components. Details of mineral-food interactions for the broad array of minerals found in foods and their interactions as well as their roles are summarized in Table 28.1.

Table 28.1. Chemical & functional roles of minerals and mineral salts/complexes in foods

Mineral	Food sources	Function
Aluminum	Low and variable in foods, component of some antacids and leavening agents	Essential nutrient: Possibly essential, evidence not conclusive. Deficiency unknown. Leavening ag ent: As sodium aluminum sulfate ($Na_2SO_4 . Al_2(SO_4)_3$) Texture modifier
Bromine	Brominated flour	Essential nutrient: Not known to be essential to humans. Doug h improver: $KBrO_3$ improves baking quality of wheat flour. It is the most used dough improver.
Calcium	Dairy products, green leafy vegetables, tofu, fish bones	Essential nutrient: Deficiency leads to osteoporosis in later life. Texture modifier: Forms gels with negatively charged macromolecules such as alginates, low-methoxy pecitns, soy proteins, caseins, etc. Firms canned vegetables when added to canning brine.

Copper	Org an meats, seafoods, nuts, seeds	Essential nutrient: Deficiency rare. Catalyst: Lipid peroxidation, ascorbic acid oxidation, nonenzymatic oxidative browning. Color modifier: May cause black discoloration in canned, cured meats. Enzyme cofactor: Polyphenoloxidase. Texture stabilizer: Stabilizes egg -white foams.
Iodine	Iodized salt, seafood, plants and animals grown in areas where soil iodine is not depleted	Essential nutrient: Deficiency produces goiter and cretinism. Doug h improver: KIO_3 improves baking quality of wheat flour.
Iron	Cereals, legumes, meat, contamination from iron utensils and soil, enriched products	Essential nutrient: Deficiency leads to anemia, impaired immune response, reduced worker productivity, impaired cognitive Development in children. Excessive iron stores may increase risk of cancer and heart disease. Catalyst: Fe^{2+} and Fe^{3+} catalyze lipid peroxidation in foods. Color modifier: Color of fresh meat depends on valence of Fe in myoglobin and hemoglobin: Fe^{2+} is red, $Fe^{3+}$is brown. Forms g reen, blue, or black complexes with polyphenoloc compounds. Reacts with S^{2-} to form black FeS in canned foods. Enzyme cofactor: Lipoxygenase, cytochromes, ribonucleotide reductase, etc.
Magnesium	Whole grains, nuts, legumes, green leafy, vegetables	Essential nutrient: Deficiency rare. Color modifier: Removal of Mg from chlorophyll changes color from green to olive-brown
Manganese	Whole grains, fruits, vegetables	Essential nutrient: Deficiency extremely rare. Enzyme cofactor: pyruvate carboxylase, superoxide dismutase.
Nickel	Plant foods	Essential nutrient: Deficiency in humans unknown. Catalyst: Hydrogenation of vegetable oils-finely divided, elemental Ni is the most widely used catalyst for this process.
Phosphates	Ubiquitous, animal products tend to be good sources	Essential nutrient: Deficiency rare due to presence in virtually all foods. Acidulent: H_3PO_4 in soft drinks. Leavening acid: $Ca(HPO_4)_2$ is a fast-acting leavening acid. Moisture retention in meats: Sodium tripolyphosphate improves moisture retention in cured meats. Emulsification aid: Phosphates are used to aid emulsification in comminuted meats and in process cheeses.
Potassium	Fruits, vegetables, meats	Essential nutrient: Deficiency rare. Salt substitute: KCl may be used as a salt substitute. May cause bitter flavor.

		Leavening agent: Potassium acid tartrate.
Selenium	Seafood, org an meats, cereals (levels vary depending on soil levels)	Essential nutrient: Keshan disease (endemic cardiomyopathy in China) was associated with selenium deficiency. Low selenium status may be associated with increased risk for cancer and heart disease. Enzyme cofactor: Glutathione peroxidase.
Sodium	NaCl, MSG, other food additives, milk; low in most raw foods	Essential nutrient: Deficiency is rare; excessive intakes may lead to hypertension. Flavor modifier: NaCl elicits the classic salty taste in foods. Preservative: NaCl may be used to lower water activity in foods. Leavening agents: Many leaving agents are sodium salts, e.g ., sodium bicarbonate, sodium aluminum sulfate, sodium acid pyrophosphate .
Sulfur	Widely distributed	Essential nutrient: A constituent of the essential amino acids methionine and cystine. Sulfur amino acids may be limiting in some diets Browning inhibitor: Sulfur dioxide and sulfites inhibit both enzymatic and nonenzymatic browning . Widely used in dried fruits. Antimicrobial: Prevents, controls microbial growth. Widely used in wine making.
Zinc	Meats, cereals	Essential nutrient: Deficiency produces loss of appetite, growth retardation, skin changes. Marginal deficiency exists in United States but extent is unknown. Pronounced deficiency was documented in populations in the Middle East. ZnO is used in the lining of cans for proteinaceous foods to lessen formation of black FeS during heating. Zn can be added to green beans to help stabilize the color during canning

Factors Affecting the Mineral Composition of Foods

Many factors interact to affect the mineral composition of foods, so compositions can vary greatly.

i) Factors Affecting the Mineral Composition of Plant Foods

In order for plants to grow, they must take up water and essential mineral nutrients from the soil. Once taken up by plant roots, nutrients are transported to other parts of the plant. The ultimate composition of the edible parts of plants is influenced and controlled by fertility of the soil, genetics of the plant, and the environment in which it grows (Fig. 28.2). The degree to which mineral content can vary even within a plant species is illustrated by wheat grain. For grain grown in Australia, North America, an the United Kingdom, zinc concentrations range from 4.5 to 37.2 mg/kg and iron from 23.6 to 74.7 mg/kg.

Adequacy of Plant Foods for Supplying the Nutrient Needs of Animals and Humans

Several questions are pertinent. Do plants and humans require the same mineral nutrients? Are the concentrations of mineral nutrients in plants sufficient to meet human requirements? Can mineral concentrations in plants be altered by agricultural or genetic means to enhance the nutritional quality of plants? Are plants grown on depleted soils nutritionally inferior to plants grown on more fertile soils? The list of essential minerals for plants is similar but not identical to the list for humans.

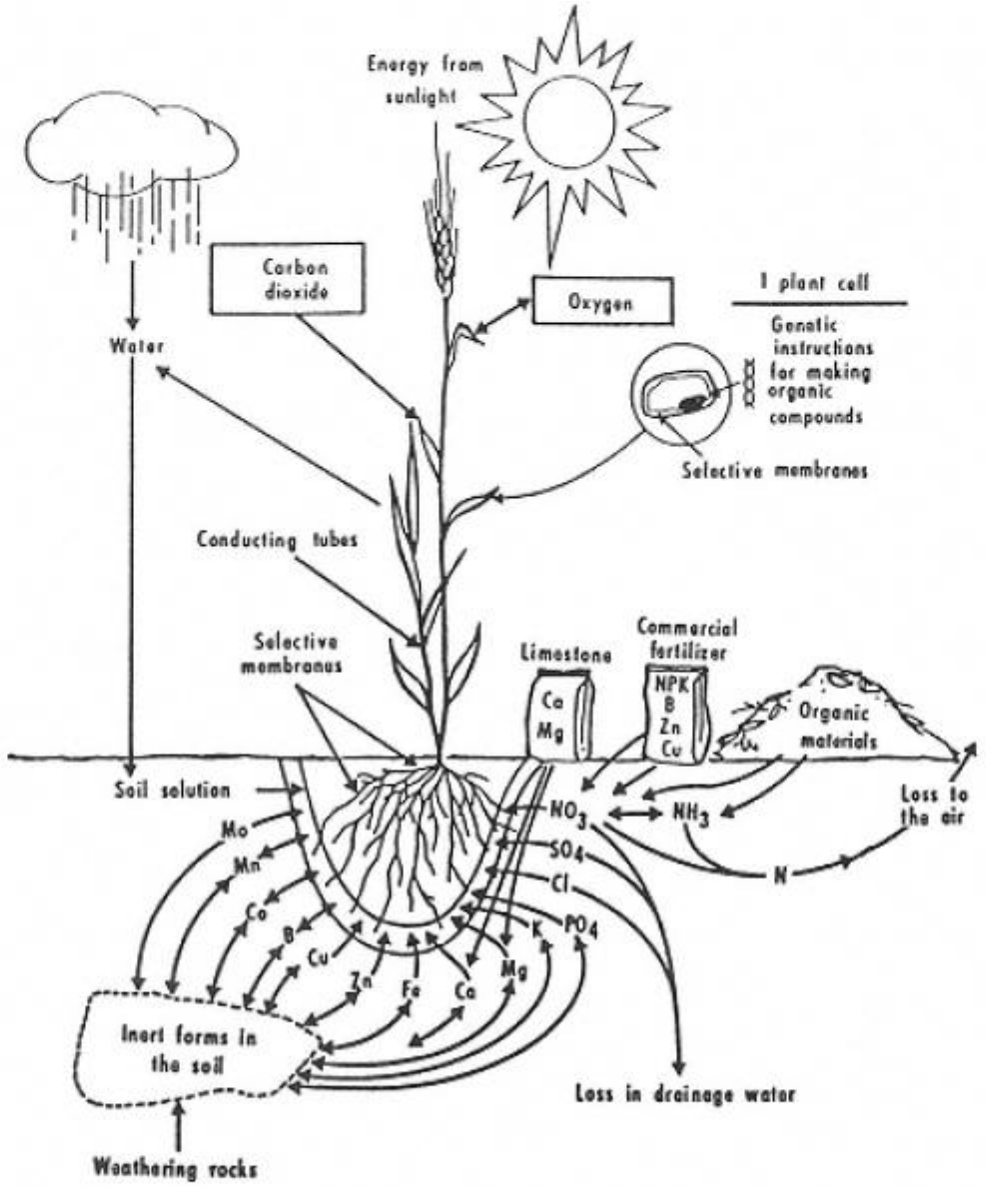

Figure 28.2. Plants obtain mineral nutrients from the soil solution surrounding the roots. Sources of these minerals include fertilizer, decaying organic materials, and weathering rocks. The minerals are taken up in the roots by a selective process and transported upward to all parts of the plant. The whole process is regulated according to instructions encoded in the plants genetic material.

F, Se, and I are essential for humans but not for most plants. Thus, we might expect to see human deficiencies of these elements in populations that depend on plants grown locally where soil concentrations of these elements are low. In fact, serious human deficiencies of selenium and iodine do exist in several areas of the world. For nutrients required by both plants and animals, we might expect human deficiencies to be less of a problem because the elements will necessarily be present in plant foods. Unfortunately, concentrations of minerals in plants are sometimes too low to meet human needs, or the minerals may be present in forms that cannot be efficiently utilized by humans (see earlier section on bioavailability). These situations apply, respectively, to calcium and iron. The calcium content of some plants is extremely low. Rice, for example, contains only about 10 mg calcium per 100 kcal. Thus, persons consuming rice-based diets must depend on other foods to meet calcium requirements. Iron is more uniformly distributed in plant foods than calcium but its bioavailability can be extremely poor, so diets based on cereals and legumes are often inadequate in iron.

While it is possible in some cases to enhance the nutritional quality of crops through agronomic practices and plant breeding, the movement of mineral nutrients from the soil to the plant and from the plant to the animal or human is an extremely complicated process. Soils differ considerably in their mineral composition. Moreover, the concentration of an element in the soil may not be a good indicator of the amount that can be taken up by plant roots, since the chemical form of the element and soil pH have marked effects on mineral bioavailability to plants. For example, increasing soil pH by adding lime will lower availability of iron, zinc, manganese, and nickel to plants and will increase availability of molybdenum and selenium. Also, plants generally possess physiological mechanisms for regulating amounts of nutrients taken up from the soil. Therefore, we might expect that attempts to alter the mineral composition of food crops would meet with mixed results. For example, application of fertilizer does not significantly increase iron, manganese, or calcium content of food crops. On the other hand, fertilization with zinc at levels in excess of the zinc requirement of the plant has been shown to increase the level of zinc in pea seeds.

ii) Factors Affecting the Mineral Composition of Animal Foods

Mineral concentrations in animal foods vary less than mineral concentrations in plant foods. In general, changes in dietary intake of the animal have only a small effect on mineral concentrations in meat, milk, and eggs. This is because homeostatic mechanisms operating in the animal regulate tissue concentrations of essential nutrients.

Adequacy of Animal Foods for Supplying the Nutrient Needs of Humans

The composition of animal tissues is similar to that of humans; thus we might expect animal foods to be good sources of nutrients. Meat, poultry, and fish are good sources of iron, zinc, phosphate, and cobalt (as vitamin B_{12}). These products are not good sources of calcium unless bones are consumed, which is usually not the case. Also, the iodine content of animal foods may be low. Dairy products are excellent sources of calcium. Thus, consumption of a variety of animal foods along with a variety of plant foods is the best way to ensure adequate intakes of all essential minerals.

Effect of food Processing on Minerals

The freshness, appearance, and nutritive value of foods changes when they are stored for long time. People in food industry work for procedures which make the foods retain their nutritive value even after a long time. The conversion of raw food materials into the acceptable food product by a variety of means is referred to as **food processing**. The techniques followed include, dehydration, freezing, heating at high temperatures, exposure to radiation (i.e. irradiation), fermentation, chemical preservation etc.

Processing of food has advantages and disadvantages both which results into desirable changes like enhancement of flavours, improvement of texture, and increase in shelf life etc. However, it may lead to some undesirable changes too. These include changes in colour, flavour, nutritional properties and development of toxicity. This affects, to some extent, all the components of food.

Minerals are comparatively stable under food processing conditions such as heat, light, use of oxidizing agents and extremes in pH. Therefore processing does not usually reduce the mineral contents. However, these minerals can be removed from foods by leaching or by physical separation. Cooking in water would result in some losses of minerals since many minerals have significant solubility in water. In general, boiling the vegetables in water causes greater loss of minerals from them as against steaming them. Canned foods such as fruit juices may take up metals from the container-tin and iron from the tin plate and tin and lead from the soldering.

During cooking sodium may be lost but the other minerals are well retained. Many selenium compounds are volatile and can be lost by cooking or processing. Further, it has been found that milling of cereals cause considerable loss of minerals. Since minerals are mainly concentrated in the bran layers and in the germ, during milling after removal of bran and germ, only pure endosperm remains, which is poor in minerals. For example, when wheat is milled to obtain refined flour, the losses in mineral content are to the extent of 76% in case of iron, 78% in zinc, 86% in manganese, 68% for copper, and 16% for selenium. Similar losses occur during milling of rice and other cereals.

As mentioned above, the minerals are quite stable to heat and pH during processing. However change in temperature, pH and concentration or dehydration may lead to the change in the status in food system. For example in milk 1/3rd 1/4th of the calcium and phosphorous is associated with casein while 66 to 80% are present as dissolved calcium and phosphorous. On heating these minerals change from the dissolved to the colloidal state. On the other hand, cooling of milk shift the colloidal calcium and phosphorous to the dissolved state. Decrease in pH from the normal value towards isoelectric side (pH 4.6) will caused the solubilization of these minerals while an increase in pH will causes a shift of colloidal calcium, magnesium and phosphorus to the dissolved state.

The minerals in meat products are in the non-fatty portions, when liquid is lost from meat, the maximum loss is of sodium and calcium, phosphorus and potassium are lost to a lesser extent. During cooking also, sodium is lost but other minerals are well retained. In fact, cooking dissolves some calcium from bone and enriches the meat with this mineral.

FORTIFICATION: NEED AND TYPES

A number of interventions are in practice that makes up for the loss of nutrients in the food. These are in terms of supplementing the food for the lost components. Nutrient supplements are added in order to:

- Maintain the nutritional availability of foods
- Provide the adequate level of nutrients in the food
- Impart additional nutritional value to the food

Nutrient supplementation obviously means adding nutrients to the food. It is generally achieved in two ways.

1. **Enrichment**: refers to adding nutrients in the food so as to maintain the amount that was present in food before its processing i.e., equal to the loss incurred during processing or preservation.

2. **Fortification:** According to FAO/WHO, Food fortification has been defined as the addition of one or more essential nutrients to a food, whether or not it is normally contained in the food, for the purpose of preventing or correcting a demonstrated deficiency of one or more nutrients in the population or specific population groups. Vitamins and minerals are most commonly used for fortification. Some of the foods and the fortifying agent used are given in Table 28.3.

Table 28.3: Some foods and the fortifying agents

S.No.	Name	Fortifying agent
1.	Salt	Iodine, iron
2.	Flours, bread, rice	Vitamin B1, B2, niacin, iron
3.	Milk, margarine	Vitamins A and D iron and calcium
4.	Sugar, monosodium glutamate, tea	Vitamin A
5.	Infant formulas, cookies	Iron, Vitamin D, E

6.	Vegetable mixtures, proteins	Vitamins, minerals
7.	Soy milk, orange juice	Calcium
8.	Ready-to-eat cereals	Vitamins, minerals
9.	Edible oils and sugar	Vitamin A

Food fortification is especially useful for the people who generally belong to low income groups and face malnutrition. Food fortification has been very successful in eradicating diseases like goitre, rickets, beriberi and pellagra. Many important aspects must be borne in mind while carrying fortification at a large scale. Some of these are as follows:

- The food selected for fortification should be the staple food of the target groups so as to make it affordable.
- The fortified nutrient should have favorable physico-chemical and bioavailability characteristics. The former takes care of the colour, taste, odour and appearance of the food while the later is important from the stability point of view. For example iron and fatty acids may react in the fortified food and produce free radicals which are not good for the quality of food.
- It should be economically viable i.e., it should not be an expensive process.
- A number of factors like the solubility and stability of the fortifying agent affect fortification. The stability depends upon pH, light and temperature besides presence of oxygen. These must be considered while attempting fortification. In addition, a proper monitoring is essential while carrying out food fortification for fruitful results.

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