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Micro-nutrient changes during food processing and storage

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The fundamental purpose of food preservation is to extend shelf life by destroying bacteria and slowing down enzyme activity. Traditional methods of preservation still in use include drying, salting and smoking. This paper reviews some of the processes through which nutrients are lost from food and suggests how these losses can be minimised. It also discusses the important concept of nutrient bioavailability and the effects of processing on bioavailability.

Conclusions and research needs

- Many of the processing-induced nutrient losses in plant foods can be avoided or minimised by careful attention to the processing and subsequent storage.
- Every day processes such as soaking, de-hulling, parboiling of rice, germination and fermentation can be used to improve the nutritional value of foods.
- Processes that remove the anti-nutritional components have a significant impact on the bioavailability of nutrients. They should be encouraged as part of the routine processing of cereals and legumes.
- Calcium, iron and zinc are the most commonly deficient minerals in the diets of infants and children in many developing countries. Their deficiency in the diet, combined with the low rates of absorption, has severe implications for growth and development. However, simple food processing techniques can help ameliorate this problem

Losses of nutrients through food processing

The term ‘food processing’ covers an enormous field – from simple boiling to the use of irradiation. A knowledge of the various food processes and the nutrient losses that occur during each process will allow improvements to be made and losses to be minimised.

Food processing has inevitable consequences on the nutritional value of foods. The macro- and micro-nutrients (carbohydrate, protein, fats, vitamins and minerals) contained within foods all show varying degrees of stability when foods are stored or processed. The degree of stability depends largely on the type and structure of the food/nutrient, food chemistry and the severity and duration of processing.

Broadly speaking, nutrients can be lost from food by one of three different means:

- intentional losses such as those that occur when cereals are milled, vegetables are peeled or individual nutrients are extracted from raw materials;
- inevitable processing losses that result from blanching, sterilising, cooking and drying foods;
- accidental losses or avoidable losses due to inefficient processing or storage systems.

Such small alterations to traditional practice can have far-reaching repercussions on the nutritional status of some poor communities.

Intentional losses due to cleaning and milling

Removal of the inedible fractions of plant foods is an essential stage of processing to improve palatability. However, these processes can incur losses of nutrients; with careful control of the processes, nutrient losses can be minimised.

Cereals

Cereals provide about three-quarters of both the energy and protein intake of the world’s population. All cereals require some form of processing prior to consumption, thereby introducing potential sources of nutrient loss. Milling, involving the mechanical separation of the endosperm from the germ, seed coat and pericarp, results in changes to the micro-nutrient composition.

Box 1: Typical nutrient composition of cereal grains (%)

	Thiamine	Riboflavin	Niacin	Protein
Pericarp and Seed coat	1	5	4	4
Aleurone	32	37	82	16
Scutellum	62	14	1	4.5
Germ	2	12	1	3.5
Total layers	97	68	88	28
Endosperm	3	32	12	72

Source: Cameron and Hofvander, 1976

Most of the B vitamins, iron and calcium are concentrated in the outer layers of grain, which are removed by milling (Box 1). After milling, flour is largely composed of the endosperm, although the composition can be varied and regulated by altering the processing conditions.

Flours can be produced to a range of different extraction rates[1], depending upon the amount of bran, germ and pericarp that are removed. Flours of high extraction rate retain many more of the micro-nutrients than those of a lower extraction rate (Box 2). When the nutritional quality of a single cereal is responsible for the health and nourishment of an entire community, particular importance needs to be paid to its milling and subsequent processing to minimise nutrient losses.

Box 2: Losses of nutrients during milling

Extraction rate	Thiamine (mg)	Riboflavin	Niacin (mg)	Protein(g)
100	0.4	0.16	5.0	13.6
85	0.35	0.08	2.0	13.6
80	0.25	0.08	1.6	13.2
70	0.08	0.05	1.1	12.8
45	0.03	0.02	0.7	11.8

Source: Bender, 1978

Because of the non-uniform distribution of nutrients throughout the grain, the nutrient losses due to processing is non-linear and is characteristic for each nutrient. Thiamine is most concentrated in the scutellum and the aleurone layer while riboflavin is more evenly spread throughout the grain, although it is predominantly concentrated in the germ. Commercial milling removes about 68% of thiamine, 58-65% of riboflavin and 85% of pyridoxine from whole wheat. Iron and zinc, which are located at the periphery of the kernel, are also considerably reduced by commercial extraction rates.

Generally, it is thought that the mineral composition of refined flour is reduced to about 30% of that of the whole grain. Despite the nutritional losses incurred by milling at low extraction rates, there is also a beneficial loss of phytic acid which is concentrated in the aleurone layer (Kent, 1974). Phytic acid forms insoluble complexes with calcium and iron, thereby reducing the bioavailability of these minerals. The reduction in phytic acid through milling may improve the bioavailability of the remaining nutrients. In populations with low calcium intake the use of 100% wholemeal flour may be a nutritional disadvantage. Three years after the introduction of 100% wholemeal flour in Dublin in 1943, the incidence of rickets rose from a negligible level to 50%. Supplementation can be achieved using calcium carbonate (chalk) in flour.

Rice

Rice cannot be consumed raw and therefore has to be processed to make it edible. The most common forms of processing are milling and polishing, both of which have implications for the nutritional quality of the final product. As with wheat, the extent of nutrient loss varies according to the severity and type of process and the distribution of nutrients within the grain.

Box 3: Approximate nutrient loss during the milling of rice (% of total)

Nutrient	Losses
Protein	15.0
Fat	85.0
Calcium	90.0
Thiamine	80.0
Riboflavin	70.0
Niacin	68.0
Pantothenic acid	62.0
Pyridoxine	56.0

Source: FAO, 1954

Legumes

Legumes provide a valuable source of protein in the diet of many of the world's poor. Most legume seeds contain between twenty to forty percent protein on a dry matter basis. This is in comparison with cereals, which contain between seven and fifteen percent protein. Despite their high nutritional value, legumes contain several anti-nutritional compounds. Processing to remove these anti-nutritional compounds is an essential stage in the preparation of most legumes.

All legumes are milled to separate the seed coat from the endosperm prior to consumption. Decortication is known to improve the absorption of water, thereby decreasing the cooking time, and removes the polyphenols and phytate present in the seed coat. Due to the reduction in polyphenols and phytates, the mineral availability from decorticated legumes is higher than from whole seeds. Soaking and cooking also reduce the levels of polyphenols (tannins) in legume seeds through leaching of the water soluble components. See the section on 'bioavailability of micro-nutrients' for further information on the roles of phytate and phenolic compounds.

Fruit and vegetables

Fruit and vegetables are a valuable source of micro-nutrients in the diets of the poor in the tropics. In regions where the consumption of animal-based foods is limited, fruit and vegetables are the predominant source of provitamin A (β-carotene). Washing and peeling result in the loss of much of the water soluble vitamins B and C since these nutrients are more concentrated in the peel and outer layers. Peeling is an essential stage of processing in most roots and tubers. To minimise losses of vitamins and minerals peeling must be minimised without affecting palatability.

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[1] The extraction rate is given as the weight of flour produced per 100g milled wheat. Therefore, an extraction rate of 100 represents milled whole grains while an extraction rate of 45 indicates a flour that is totally endosperm.

Parboiling as a technique to reduce nutrient loss in rice

Parboiling is a technique used to process rice and which is claimed to improve the retention of proteins, vitamins and minerals during subsequent cooking. Raw rice is soaked in water and partially steamed prior to drying and milling. The effects of parboiling on the retention of nutrients within the grain are two-fold. Some B vitamins migrate further into the grain, thus reducing their loss during milling. It is reported that parboiled rice may contain up to 2µg/g of thiamine compared to only 0.7 µg/g for the untreated grain (Bender, 1978). Secondly, as the grain becomes partially gelatinised during processing, it is less susceptible to damage during milling and has improved keeping qualities. The protein quality of parboiled rice is also slightly improved (Box 4).

Box 4: Effect of parboiling on rice quality

	Raw	Parboiled
Thiamine	0.7µg	2.0µg
Protein		
NPU[2]	0.78	0.81
PER	1.4	1.7

Source: Bender, 1978

A modified technique, known as *converted rice* has been used to reduce vitamin losses in rice and to provide an alternative to parboiling. Converted rice undergoes a vacuum treatment while soaking, followed by steaming under pressure. This technique has the advantage of avoiding the characteristic taint of parboiled rice, but is probably unsuitable for use at the household level by the poorest communities due to the unavailability of pressure cooking facilities. The vitamin content of converted rice is similar to that of parboiled rice, with approximately five times more thiamine and niacin than untreated rice, three times more B6, riboflavin and pantothenate and twice the amount of biotin (Bender, 1978).

In addition to milling and polishing, washing of rice prior to cooking is another potential source of nutrient loss. In most Asiatic countries, rice is washed or soaked in water for lengthy periods prior to cooking. During this time, considerable amounts of water soluble vitamins (B group) are leached out into the wash water, which is then discarded (Juliano, 1993). Washing for shorter periods of time will help to conserve some of these water soluble vitamins.

Inevitable losses due to processing and cooking.

Cooking and food processing have both positive and negative effects on the nutritional value of foods. The digestibility of proteins and starches is improved by cooking and many anti-nutritional components are destroyed. However, there is some inevitable leaching of nutrients into the cooking water during processing and cooking.

Dark green leafy vegetables are an important source of β-carotene, the precursor of vitamin A. However, processing and cooking can result in significant losses of this compound. Boiling leafy vegetables results in higher losses than both steaming and frying (Box 5).

Box 5: The effect of processing on β-carotene in vegetables

Foods	Treatments	Total Carotene µg/100g	Beta-carotene µg/100g	Percentage Loss	
				Total Carotene	Beta-Carotene
Drumstick leaves	Raw	39,820	29,444	-	-
	Boiling	13,056	8,580	67.2	70.8
	Steaming	13,248	8,717	66.7	70.3
	Shallow fat frying	12.054	10,280	69.7	65.0
Mullakeerai	Raw	19,032	12,714	-	-
	Boiling	11,352	4,556	40.4	64.2
	Steaming	16,524	10,155	13.2	20.1
	Shallow fat frying	15,752	10,830	17.3	14.8
Thandukeerai	Raw	18,048	7,488	-	-
	Boiling	15,920	6,070	11.8	18.9
	Steaming	15,600	7,059	13.6	5.7
	Shallow fat frying	10,688	7,200	40.7	3.9
Carrot	Raw	8,344	4,406	-	-
	Boiling	7,296	2,990	12.6	32.1
	Steaming	7,640	4,323	8.4	1.9
	Shallow fat frying	7,416	4,023	11.3	8.7
Pumpkin	Raw	2,050	1,599	-	-
	Boiling	1,186	819	42.1	48.8
	Steaming	1,314	1,190	35.9	25.6
	Shallow fat frying	1,720	1,237	16.1	22.7

Blanching

Blanching is used to inactivate enzymes as a pre-requisite to the preservation of vegetables. Blanching can be carried out by immersion in boiling water or by treatment with hot air or steam. Boiling water is the most common form of blanching used at the small scale. Nutrient retention during blanching differs according to the method used and the type and size of vegetable. Inevitably there is some loss of water soluble nutrients such as mineral salts, protein, sugar and vitamins during the blanching and subsequent water cooling, but these can be kept to a minimum by attention to detail. Losses are greater from food with a large surface to volume ratio. The loss of nutrients is not uniform throughout the

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[2] NPU and PER represent the Net Protein Utilisation and Protein Efficiency Ratio, both of which are measures of protein quality.

blanching period, with most losses occurring in the early stages.

Accidental losses through improper processing and storage

Fluctuations in temperature and humidity, undue access to air and insect or rodent infestation during storage all result in considerable nutrient losses. These are all unnecessary losses that could be reduced or avoided with efficient storage methods.

At optimum storage conditions (ambient temperature of 15 to 18°C and low moisture content) cereals can be stored for long periods with no significant effect on nutrient composition. Milling and polishing of rice is known to increase the susceptibility to nutrient damage during storage.

Bioavailability of micro- nutrients

Nutritionists now recognise that only a proportion of the nutrients ingested are biologically available (Gibson, 1994). This is due to a number of reasons related to the physical nature and chemical composition of foods and to the individual's digestive capacity. One of the most important factors seems to be the presence of dietary components that interfere with digestion and inhibit absorption of some nutrients. Bioavailability can be influenced by simple processing, which is discussed in detail in the following section.

Calcium, iron and zinc are the most commonly deficient minerals in the diets of infants and children in many developing countries. Their deficiency in the diet, combined with the low rates of absorption, has severe implications for growth and development. However, simple food processing techniques can help ameliorate this problem.

Dietary fibre and mineral availability

Dietary fibre, also known as non-starch polysaccharides, is the fraction of plant material that is resistant to digestion by humans to some degree. These are composed of a number of materials; cellulose, hemicellulose, gums, pectins, mucilages, lignin and waxes. The fibre content of cereals may be as high as 16%, while in fruit and vegetables is between 1-10%. The types of fibre present in fruit and vegetables differ considerably from those in cereals, the former being largely water soluble pectins and hemi-celluloses while in the latter the majority of fibre is non-soluble cellulose and lignin. The various fibre fractions have different effects within the gut and on the bioavailability of nutrients. The water soluble pectins and gums have a high water holding capacity and tend to slow the passage of food through the gut. Thus, they are valued for their ability to satiate hunger. The non-soluble components – cellulose and lignins in particular – act as bulking agents, but speed the passage of food through the gut, thus reducing the capacity for absorption of nutrients. It is these components that are most frequently associated with the reduced bioavailability of nutrients. Extensive *in vivo* and *in vitro* studies have demonstrated that the cellulose and bran fractions of dietary fibre from soy, corn, wheat and rice bind minerals and reduce their availability (Camire and Clydesdale, 1981).

The diets of poor communities in developing countries tend to be based on a local staple, which is often bulky and high in dietary fibre. Thus, although the diets are filling, they may have undesirable effects on the bioavailability of already scarce macro and micro-nutrients.

The bioavailability of micro-nutrients also appears to be influenced by the interaction between fibre and other food components such as tannins, phytates, oxalates and citrates. Sandstrom *et al.* (1984) have suggested that the presence of phytic acid in fibre may be more important in mineral availability than the fibre levels *per se*. Recent studies seem to suggest that pure fibre fractions have little effect on mineral availability. For example, cellulose or pectins added to diets appears to have little or no effect on zinc absorption and the use of mucilages and gums in food systems has little or no effect on iron bioavailability (Cook *et al.*, 1983). Since fibre is usually associated with compounds such as phytates and polyphenols, it is suggested that these compounds are responsible for binding the minerals.

Several other food components are known to interact with dietary fibre and to have an effect on the availability of minerals. Ascorbic acid and certain amino acids are known to enhance the absorption of iron, while tannins and phytate inhibit the absorption. The bioavailability of iron may be facilitated or decreased by chelating agents which are used as intentional food additives. The most widely used chelating agent is EDTA, which is added to prevent oxidative damage by free radicals. The availability of iron from foods is also influenced by the type of iron (Fe^{2+}/Fe^{3+}), the particle size of the iron used in fortification and by the presence of other nutrients within the food.

Phytates

Fibre rich foods, including both cereals and legumes, contain high levels of phytate or phytic acid. Phytic acid is the storage form of phosphorus in cereals and is released when the grain germinates. It is usually located in the outer layer of cereals and legumes, which is where the fibre is primarily concentrated. During the milling of cereals and decortication of legumes, most of the phytate is removed.

Phytates form insoluble complexes with many minerals, notably zinc, iron, magnesium and calcium at physiological pH. The inhibitory effect of phytate on mineral bioavailability seems to be dose dependent, with even small amounts having a strong inhibitory effect. A reduction of dietary phytates causes dramatic increases in mineral bioavailability (Hallberg, 1987). Gibson *et al.,* (1994) showed that the molar ratio of phytate to zinc is important in determining the bioavailability of zinc. A phytate to zinc ratio greater than 15 is associated with an increased risk of zinc deficiency. Unrefined cereals have a high phytate content but are also rich in minerals. Diets based on rice and maize have an elevated ratio, indicating poor nutrient availability. There is considerable variability in the amount of phytates consumed the world over. In many developing countries, diets based on legumes and cereals will contain up to 600 mg phytate per day compared to 170 mg per day in North American diets (Ellis *et al.*, 1987).

Phenolic compounds (Tannins)

Phenolics cover a range of compounds including flavenoids, phenolic acid, polyphenols and tannins. They are widely distributed throughout the plant kingdom and are found in tea, vegetables (e.g. legumes, aubergines), cereals (sorghum) and many seeds. Phenolic compounds are important nutritionally since they bind with nutrients such as iron and proteins, reducing their availability (Gillooly *et al.*, 1984). Numerous studies have shown that tannin in tea, coffee and wine can bind iron (Hallberg and Rossander, 1982) and has been linked to iron deficiency in children (Merhav *et al.*, 1985). In some cereals such as sorghum, phenolic compounds bind iron and proteins. Ingestion of ascorbic acid appears to counteract the inhibitory effect of tannins on iron bioavailability (Gillooly *et al.*, 1984). If ascorbic acid is oxidised (during warm holding of food), its enhancing effect on iron absorption is greatly diminished (Fretzdorff, 1993). Therefore, ascorbic acid in the form of an accompanying citrus drink is more effective in increasing iron absorption than incorporation into the meal. The addition of citric, lactic, tartaric, or malic acid to rice meal also improves iron bioavailability (Gillooly *et al.,* 1983).

Tannins are mainly located in the bran of cereal grains and the seed coat or testa of legumes. Aside from the formation of tannin-mineral complexes, they also interact with proteins and enzymes, increasing the excretion of proteins and essential amino acids. As most tannins are located in the seed coat or testa, dehulling or milling is a good method of removal.

Processing to improve bioavailability

Simple processing methods can be used to reduce the level of phytates and thus improve mineral bioavailability. Soaking the grain or legume in water of optimum pH (around 5.5 for soybean), cooking the soaked seeds and germination of the raw seeds are known to reduce phytate content. Both bread making and germination are frequently used to reduce the effects of phytates on mineral absorption.

Germination

Germination of cereals and legumes is known to improve the vitamin and mineral content (Chavan and Kadam, 1989). Moreover, it has been shown to reduce the levels of phytate, tannins and oxalates in cereals. Vitamin C and riboflavin are synthesised during germination therefore legumes are often germinated until they sprout. The shoots should be consumed raw or minimally processed since these vitamins are lost during cooking. During germination phytic acid is hydrolysed by phytase, an enzyme present in the aleurone layer of the kernel. The activity of phytase is enhanced by the presence of yeast, thus during the bread making process the levels of phytate within wheat are reduced considerably (Ranhotra, 1973).

Box 6 illustrates the effects of several simple food processes on the phytate content of lentil seeds.

Box 6: The effect of different processes on phytic acid content of lentils

Variety and Treatment	Phytic Acid (mg/g)	Difference	Reduction (%)
L. culinaris var. Vulgaris Unprocessed	6.2 ± 0.01		
Water soaked	4.5 ± 0.03	1.7	27
Water soaked and cooked	3.8 ± 0.01	2.4	39
Citric acid soaked	3.9 ± 0.01	2.3	37
Citric acid soaked and cooked	4.2 ± 0.01	2.0	32
Sodium bicarbonate soaked	4.8 ± 0.01	1.4	23
Sodium bicarbonate soaked and cooked	4.4± 0.01	1.8	29
Germinated	2.1 ± 0.01	4.1	66
L. culinaris var. Variabilis Unprocessed	8.1 ± 0.01		
Germinated	4.5 ± 0.01	3.6	44

Source: Vidal-Valverde *et al.*, 1994

Fermentation

Fermentation is another widely practised form of food processing that is effective in removing anti-nutritional components from cereals and legumes while improving their digestibility and sensory characteristics (Reddy and Pierson, 1994). Fermentation has a number of benefits. Enzymes produced by micro-organisms break down the starches and proteins into sugars and constituent amino acids. Levels of riboflavin, niacin and methionine are increased, and vitamin B12 is synthesised. There is also an increase in the amount of available iron (Ackroyd and Doughty, 1964). Fermentation activates the enzyme phytase, thus promoting the hydrolysis of phytic acid. During bread making, 92% of phytate hydrolysis occurs during the fermentation stage compared to only 10% in non-leavened bread (Ranhotra, 1972; Reddy and Pierson, 1994). This difference is attributed to the presence of yeast in the former, which provides favourable conditions for the hydrolysis of phytate. Box 7 illustrates the effect of fermentation on the phytate content of maize.

Box: 7 The effect of fermentation on phytate level of maize during the preparation of kenkey

	Phytate	
	Content (mg/g)	Hydrolysed (%)
Ghanaian maize		
Raw maize	9.13	
Steeped maize	8.60	5.9
Fermented dough	7.59	16.9
Kenkey	7.54	17.4
Malawi maize		
Raw maize	7.14	
Steeped maize	6.99	2.2
Fermented dough	6.95	2.7
Kenkey	4.92	31.1

Source: Reddy and Pierson, 1994

Conclusions

The processing of food is necessary to improve palatability and to extend its shelf life. Inevitably, processing leads to some nutrient losses. These can be minimised or avoided by careful attention to the process and subsequent storage. This is especially significant for communities in developing countries where diets are deficient in some nutrients. Everyday processes such as soaking, de-hulling, parboiling of rice, germination and fermentation can be used to improve the nutritional value of foods. Simple food processes that remove the anti-nutritional components such as phytates and phenolic compounds have a significant impact on the bioavailability of nutrients. They should be encouraged as part of the routine processing of cereals and legumes.

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