# WATER-SOLUBLE VITAMINS

Vitamin C (L-ascorbic acid)

- This vitamin occurs in all living tissues, where it influences oxidation-reduction reactions.

- L-ascorbic acid is a lactone (internal ester of a hydroxycarboxylic acid) and is characterized by the enediol group, which makes it a strongly reducing compound.

- The D form has no biological activity.

- One of the isomers, D-isoascorbic acid, or erythorbic acid, is produced commercially for use as a food additive.
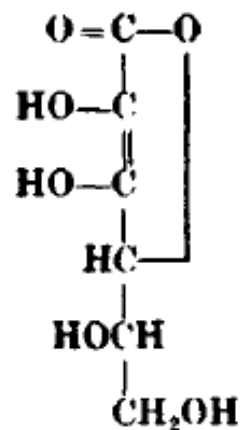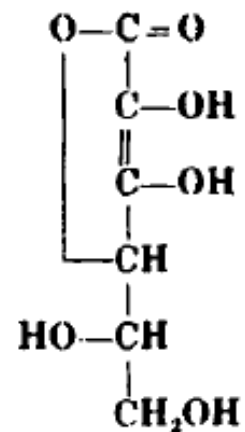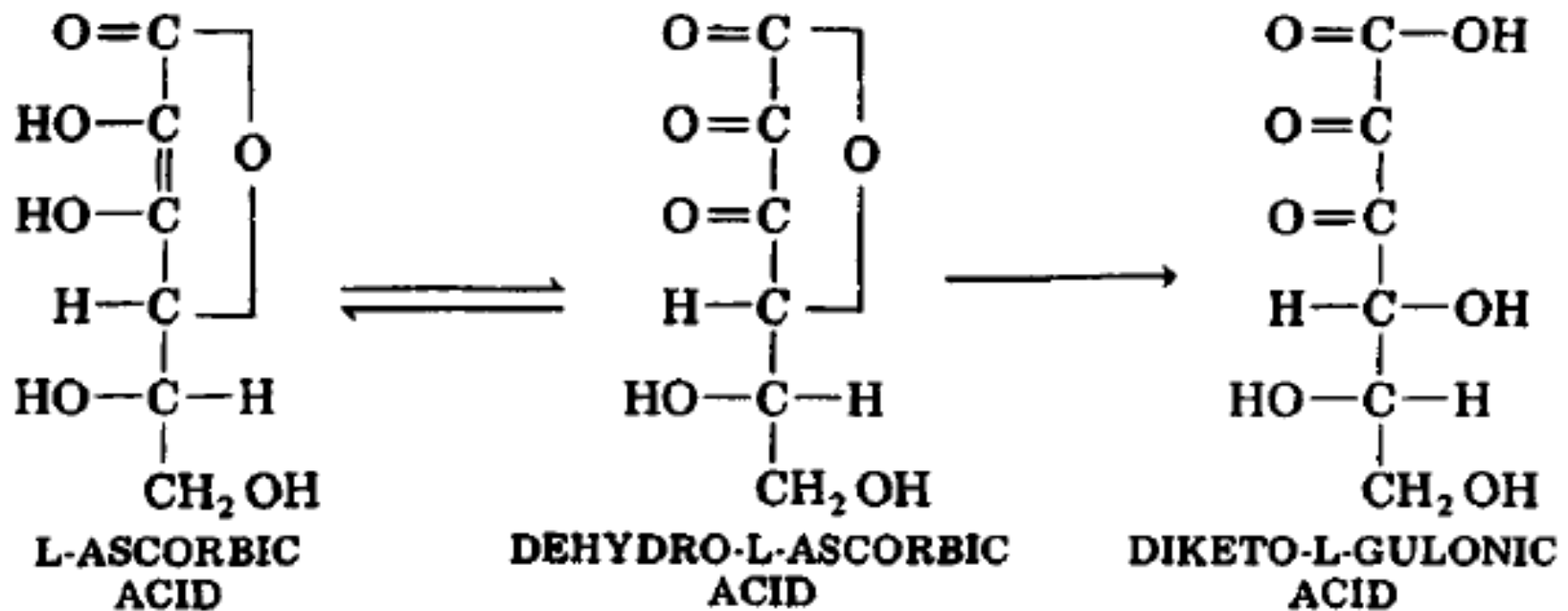
L-ASCORBIC ACID
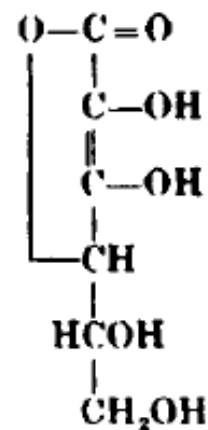
D-ASCORBIC ACID
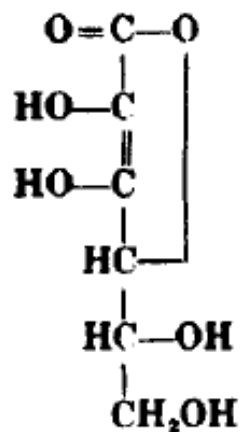
D-ISOASCORBIC ACID
(ERYTHORBIC ACID)

L-ARABOASCORBIC ACID

Structural Formulas of L-Ascorbic Acid and Its Stereoisomers

- L-ascorbic acid is readily and reversibly oxidized to dehydro- L-ascorbic acid, which retains vitamin C activity. This compound can be further oxidized to diketo-L-gulonic acid, in a nonreversible reaction.

Oxidation of L-Ascorbic Acid

- Diketo-L-gulonic acid has no biological activity, is unstable, and is further oxidized to several possible compounds, including 1-threonic acid.
- Dehydration and decarboxylation can lead to the formation of furfural, which can polymerize to form brown pigments or combine with amino acids in the Strecker degradation.

Vitamin C Sources

- Vitamin C is widely distributed in nature, mostly in plant products such as fruits (especially citrus fruits), green vegetables, tomatoes, potatoes, and berries.
- The only animal sources of this vitamin are milk and liver.
- Although widely distributed, very high levels of the vitamin occur only in a few products.
- The concentration varies widely in different tissues of fruits; for example, in apples, the concentration of vitamin C is two to three times as great in the peel as in the pulp.

Table 9–13 Vitamin C Content of Some Foods

Product	Ascorbic Acid (mg/100 g)
Black currants	200
Brussels sprouts	100
Cauliflower	70
Cabbage	60
Spinach	60
Orange	50
Orange juice	40–50
Lemon	50
Peas	25
Tomato	20
Apple	5
Lettuce	15
Carrots	6
Milk	2.1–2.7
Potatoes	30

The stability of Vitamin C

- Vitamin C is the least stable of all vitamins and is easily destroyed during processing and storage.
- The rate of destruction is increased by: the action of metals, especially copper and iron, and by the action of enzymes (especially enzymes containing copper or iron, such as ascorbic acid oxidase, phenolase, cytochrome oxidase, and peroxidase).
- Exposure to oxygen, prolonged heating in the presence of oxygen, and exposure to light are all harmful to the vitamin C content of foods.

- Blanching can be used to prevent degradation of ascorbic acid caused by enzimatic reaction.

- In fruit juices, the enzymes can be inhibited by pasteurization, deaeration, or holding at low temperature for a short period.

Table 9–14 Effect of Blanching Method on Ascorbic Acid Levels of Broccoli

Factor Effect	Ascorbic Acid (mg/100 g)		
	Reduced	Dehydro	Total
Raw	94.0	4.0	98.2
Water blanch	45.3	5.7	51.0
Steam blanch	48.8	7.4	56.2

Source: From D. Odland and M.S. Eheart, Ascorbic Acid, Mineral and Quality Retention in Frozen Broccoli Blanched in Water, Steam, and Ammonia-Steam, *J. Food Sci.*, Vol. 40, pp. 1004–1007, 1975.

- Ascorbic acid is oxidized in the presence of air under neutral and alkaline conditions.
- At acid pH (for example, in citrus juice), the vitamin is more stable.
- Because oxygen is required for the breakdown, removal of oxygen should have a stabilizing effect. For the production of fruit drinks, the water should be de-aerated to minimize vitamin C loss.
- Container also influence the loss of vitamin C (products packed in tin can and bottle are more susceptible to oxidation).

- Light results in rapid destruction of ascorbic acid in milk --- transparent packaging materials permit rapid destruction of vitamin C.
- The extent of ascorbic acid destruction is closely parallel to the development of off-flavors.
- The destruction of ascorbic acid in milk by light occurs under the influence of riboflavin as a sensitizer.
- The reaction occurs in the presence of light and oxygen, and the riboflavin is converted to lumichrome.

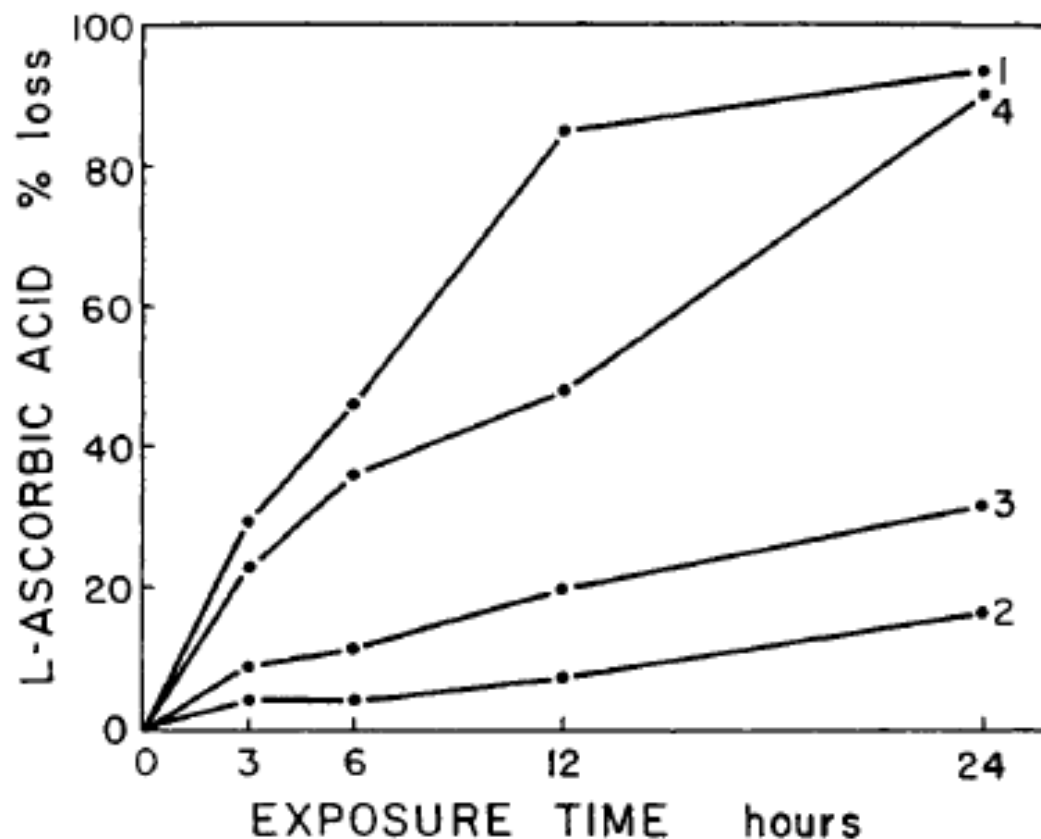**Figure 9–11** Effect of Exposure Time at Light Intensity of 200 Ft-C on the Loss of Ascorbic Acid in Milk. Packaging materials: (1) clear plastic pouch, (2) laminated nontransparent pouch, (3) carton, (4) plastic 3-quart jug. *Source:* From A. Sattar and J.M. deMan, Effect of Packaging Material on Light-Induced Quality Deterioration of Milk, *Can. Inst. Food Sci. Technol. J.*, Vol. 6, pp. 170–174, 1973.

- Factors that affect vitamin C destruction during processing include heat treatment and leaching.
- The extent of loss depends on the amount of water used and particle size of foods.
- The processing of milk into various dairy products may result in vitamin C losses.
  - Ice cream contains no vitamin C, nor does cheese.
  - The production of powdered milk involves a 20-30% loss, evaporated milk a 50-90% loss.
  - Adding 266 mg of sodium ascorbate per kg in evaporated milk was sufficient to ensure the presence of at least 140 mg/L of ascorbic acid during 12 months of storage at 21^0C.

- Vitamin C Stability in Fortified Foods and Beverages after Storage at 23^{0}C for 12 Months, Except as Noted

Product	No. of Samples	Retention Mean (%)	Retention Range (%)
Ready-to-eat cereal	4	71	60–87
Dry fruit drink mix	3	94	91–97
Cocoa powder	3	97	80–100
Dry whole milk, air pack	2	75	65–84
Dry whole milk, gas pack	1	93	—
Dry soy powder	1	81	—
Potato flakes[1]	3	85	73–92
Frozen peaches	1	80	—
Frozen apricots[2]	1	80	—
Apple juice	5	68	58–76
Cranberry juice	2	81	78–83
Grapefruit juice	5	81	73–86
Pineapple juice	2	78	74–82
Tomato juice	4	80	64–93
Vegetable juice	2	68	66–69
Grape drink	3	76	65–94
Orange drink	5	80	75–83
Carbonated beverage	3	60	54–64
Evaporated milk	4	75	70–82

[1]Stored for 6 months at 23°C.
[2]Thawed after storage in freezer for 5 months.

Source: From E. deRitter, Stability Characteristics of Vitamins in Processed Foods, Food Technol., Vol. 30, pp. 48–51, 54, 1976.

The application of vitamin C in food processing

- Vitamin C is used to prevent browning and discoloration in vegetables and fruit products;
- as an antioxidant in fats, fish products, and dairy products;
- as a stabilizer of color in meat;
- as an improver of flour;
- as an oxygen acceptor in beer processing;
- as a reducing agent in wine, partially replacing sulfur dioxide; and
- as an added nutrient.

Vitamin B1 (Thiamin)

- Thiamin acts as a coenzyme in the metabolism of carbohydrates and is present in all living tissues.
- Thiamin is available in the form of its chloride or nitrate
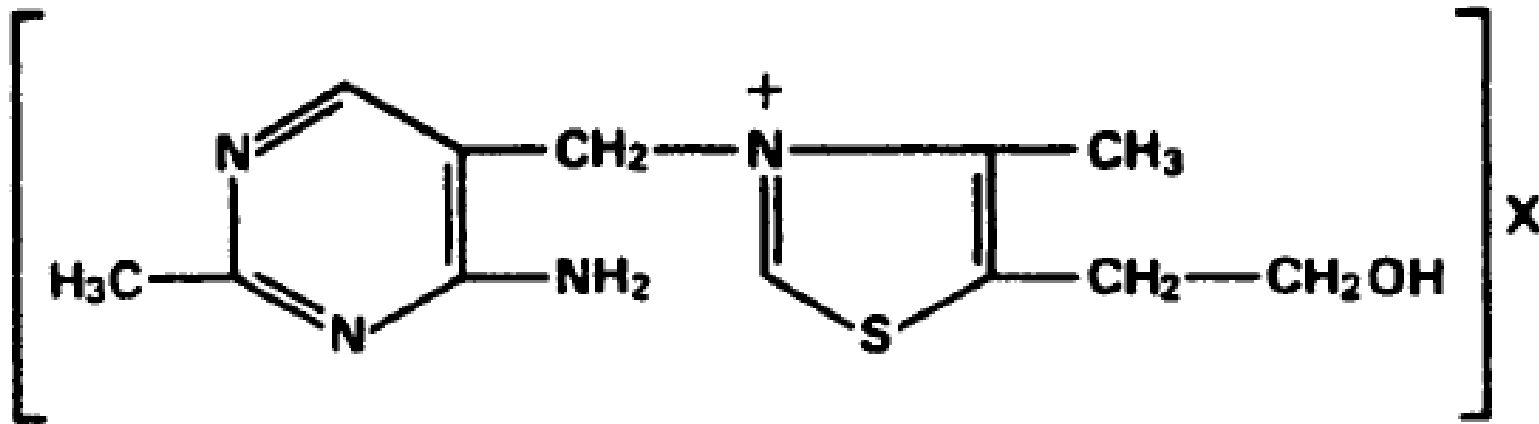
Structural Formula of Thiamin.

Hydrochloride: X = Cl , HCl⁻ ; Mononitrate: X = NO₃⁻

The chemical structure of thiamin

- The molecule contains two basic nitrogen atoms; one is in the primary amino group, the other in the quarternary ammonium group.
- It forms salts with inorganic and organic acids.
- The vitamin contains a primary alcohol group, which is usually present in the naturally occurring vitamin in esterified form with ortho-, di-, or triphosphoric acid.
- In acid solution, the equilibrium favors the formation of positive ions.

- The thiol- form is favored in alkaline medium. This form can react with compounds containing sulfhydryl groups to form disulfide bridges. It has been suggested that thiamin occurs in some foods linked to protein by disulfide bridges.

positive ions   Pseudobase   Thiol form

acid ←——————————————————————————→ alkaline
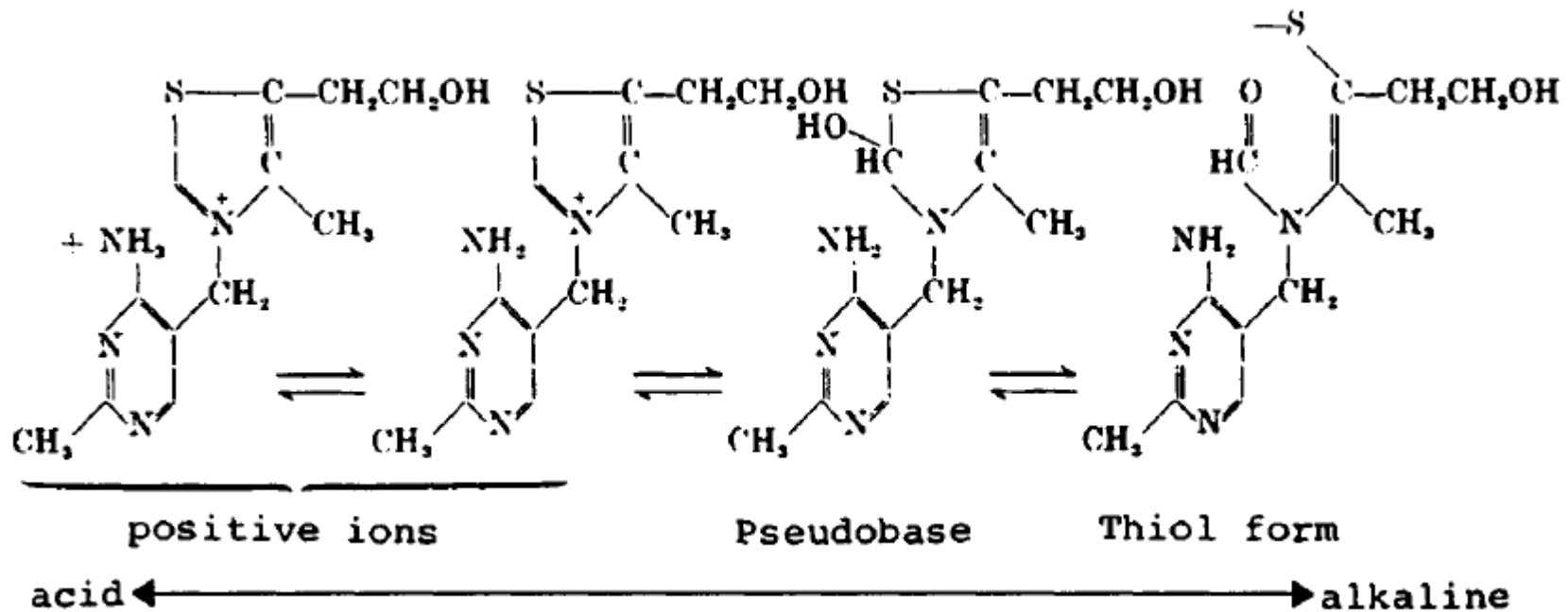
Table 9–16 Thiamin Content of Some Foods

Product	Thiamin (mg/100 g) Edible Portion
Almonds	0.24
Corn	0.37
Egg	0.11
Filberts	0.46
Beef heart	0.53
Beef liver	0.25
Macaroni (enriched)	0.88
Macaroni (not enriched)	0.09
Milk	0.03
Peas	0.28
Pork, lean	0.87
Potatoes	0.10
Wheat (hard red spring)	0.57
Wheat flour (enriched)	0.44
Wheat flour (not enriched)	0.08

The sources of thiamin

● Although thiamin content is usually measured in mg per 100 g of a food, another unit has been used occasionally, the IU corresponding to 3 ug of thiamin-hydrochloride.

The stability of thiamin

- Thiamin is one of the more unstable vitamins.
  - ○ Various food processing operations may considerably reduce thiamin levels (for examples: baking, pasteurization, sterilization, drying, milling, cooking, boiling, roasting and canning).
  - ○ Heat, oxygen, sulfur dioxide, leaching, and neutral or alkaline pH may all result in destruction of thiamin.
- Light has no effect.
- The enzyme is stable under acid conditions

Table 9–18 Thiamin Stability in Foods

Product	Treatment	Retention (%)
Nine canned vegetables	Processing	31–89
Four canned vegetables	Storage, 2–3 mo @ room temperature	73–94
Cereals	Extrusion cooking	48–90
Fortified ready-to-eat cereal	Storage, 12 mo @ 23°C	100
Bread (white, whole wheat)	Commercial baking	74–79
Devil's food cake (pH 9)	Baking	0–7

Table 9–17 Nutrients and Levels Recommended for Inclusion in Fortification of Cereal-Grain Products[1]

Nutrient	Level (mg/lb)	Level (mg/100 g)
Vitamin A[2]	2.2	0.48
Thiamin	2.9	0.64
Riboflavin	1.8	0.40
Niacin	24.0	5.29
Vitamin B_6	2.0	0.44
Folic acid	0.3	0.07
Iron	40	8.81
Calcium	900	198.2
Magnesium	200	44.1
Zinc	10	2.2

[1]Wheat flour, corn grits, cornmeal, rice. Other cereal-grain products in proportion to their cereal-grain content.
[2]Retinol equivalent.

Vitamin B2 (Riboflavin)

● The molecule consists of a d-ribitol unit attached to an isoalloxazine ring.
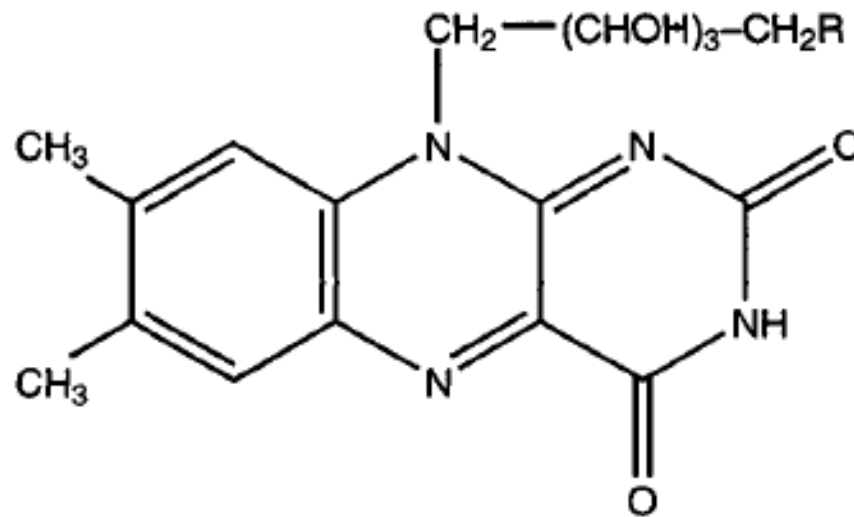

Figure 9–15 Structural Formula of Riboflavin.
Riboflavin: R = OH; Riboflavin phosphate: R = PO_3NaOH.

- A minor change in the molecule results in a loss of vitamin activity.

- Aqueous solutions of riboflavin are yellow with a yellowish-green fluorescence.

- The vitamin is a constituent of **two coenzymes**, **flavin mononucleotide (FMN)** and **flavin adenine dinucleotide (FAD)**.

- FMN is riboflavin-5'-phosphate and forms part of several enzymes, including cytochrome creductase.
- The flavoproteins serve as electron carriers and are involved in the oxidation of glucose, fatty acids, amino acids, and purines.
- In most cases, the riboflavin of foods is present in the form of the dinucleotide, the phosphoric acid ester, or is bound to protein.
- Only in milk does riboflavin occur mostly in the free form.

The sources of riboflavin

Table 9–19 Riboflavin Content of Some Foods

Product	Riboflavin (mg/100 g) Edible Portion
Beef	0.16
Cabbage	0.05
Eggs	0.30
Chicken	0.19
Beef liver	3.26
Chicken liver	2.49
Beef kidney	2.55
Peas	0.29
Spinach	0.20
Tomato	0.04
Yeast (dry)	5.41
Milk	0.17
Nonfat dry milk	1.78

The stability of riboflavin

- Riboflavin is stable to oxygen and acid pH.
- But it is unstable in alkaline medium and very sensitive to light.
  - When exposed to light, the rate of destruction increases as pH and temperature increase.
    - The wavelengths of light responsible for the riboflavin destruction are in the visible spectrum below 500 to 520 nm.
    - Ultraviolet light has been reported to have destructive effect on riboflavin.
  - Heating under neutral or acidic conditions does not destroy the vitamin.

- Under the influence of light and alkaline pH, riboflavin is transformed into lumiflavin, an inactive compound with a yellowish green fluorescence (→ in milk it can cause the degradation of ascorbic acid)
- Under acid conditions, riboflavin is transformed into another inactive derivative, lumichrome, and ribitol. This compound has a blue fluorescence.

- The light sensitivity of riboflavin results in losses of up to 50 percent when milk is exposed to sunlight for two hours.
- The nature of the packaging material significantly affects the extent of riboflavin destruction.
- Riboflavin is stable in dry milk for storage periods of up to 16 months.
- Pasteurization of milk causes only minor losses of riboflavin.

Vitamin B6 (Pyridoxine)

- There are three compounds with vitamin B6 activity, i.e. pyridoxine, pyridoxal and pyridoxamine.

- Pyridoxal has a -CHO group in carbon 4 of the benzene ring and pyridoxamine has a -CH_2NH_2 group.

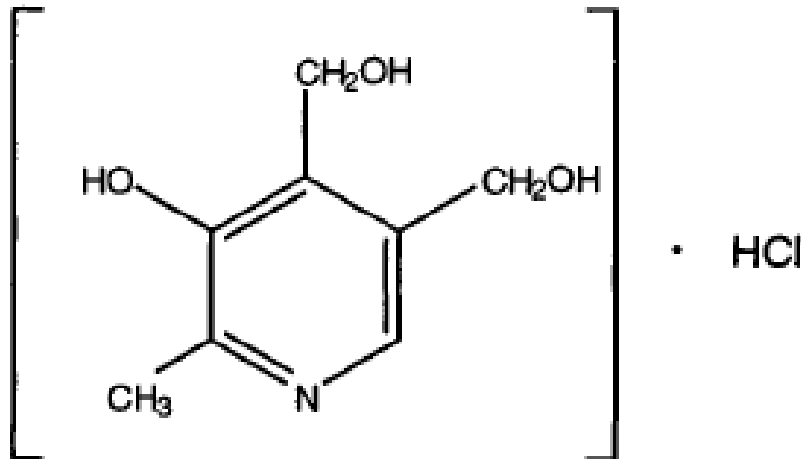- All three compounds can occur as salts.

Figure 9–16 Structural Formula of Pyridoxine

- Vitamin B6 plays an important role in the metabolism of amino acids, where it is active in the coenzyme form pyridoxal-5-phosphate.
- The three forms of vitamin B6 are equally active in rats.

The source of vitamin B6

- Vitamin B6 occurs in animal tissues in the form of pyridoxal and pyridoxamine or as their phosphates.
- Pyridoxine occurs in plant products.
- The level in milk as 0.54 mg per liter.
- Other sources are meats, liver, vegetables, whole grain cereals, and egg yolk.

Table 9–20 Vitamin B_6 Content of Some Foods

Product	Vitamin B_6 ($\mu g/g$)
Wheat	3.2–6.1
Whole wheat bread	4.2
White bread	1.0
Orange juice	0.52–0.60
Apple juice	0.35
Tomatoes	1.51
Beans, canned	0.42–0.81
Peas, canned	0.44–0.53
Beef muscle	0.8–4.0
Pork muscle	1.23–6.8
Milk, pasteurized	0.5–0.6
Yeast	50

The stability of vitamin B6

- Pyridoxine is stable to heat and strong alkali or acid; it is sensitive to light, especially ultraviolet light and when present in alkaline solutions.
- Pyridoxal and pyridoxamine are rapidly destroyed when exposed to air, heat, or light.
- Pyridoxamine is readily destroyed in food processing operations.

- No significant losses of pyridoxine have been reported to result from pasteurization, homogenization, or production of dried milk.
- Heat sterilization of milk, however, has been reported to result in losses ranging from 36 – 49%.
- Losses occur not only during the heat treatment but also during subsequent storage of milk.
- These storage losses have been attributed to a conversion of pyridoxal to pyridoxamine and then to a different form of the vitamin, i.e. *bis*-4-pyridoxal disulfide.

- Exposure of milk to daylight in clear glass bottles for eight hours resulted in a vitamin B6 loss of 21 percent.
- Food canning results in losses of vitamin B6 of 20 to 30 percent.
- Milling of wheat may result in losses of up to 80 to 90 percent.
- Baking of bread may result in losses of up to 17 percent.

Table 9–21 Vitamin B_6 Stability in Foods

Product	Treatment	Retention (%)		
		Saccharomyces Carlsbergensis	Chick	Rat
Bread (added B_6)	Baking	100		
Enriched corn meal	12 mo @ 38°C + 50% relative humidity	90–95		
Enriched macaroni	12 mo @ 38°C + 50% relative humidity	100		
Whole milk	Evaporation and sterilization	30	55	65
	Evaporation and sterilization + 6 mo @ room temperature	18	44	41
Infant formula, liquid	Processing and sterilization	33–50 (natural) 84 (added)		
Infant formula, dry	Spray drying	69–83		
Boned chicken	Canning	57		
	Irradiation (2.79 megarads)	68		

Niacin

- The term *niacin* is used in a generic sense for both nicotinic acid and nicotinamide.

- Nicotinamide acts as a component of two important enzymes, NAD and NADP, which are involved in glycolysis, fat synthesis, and tissue respiration.
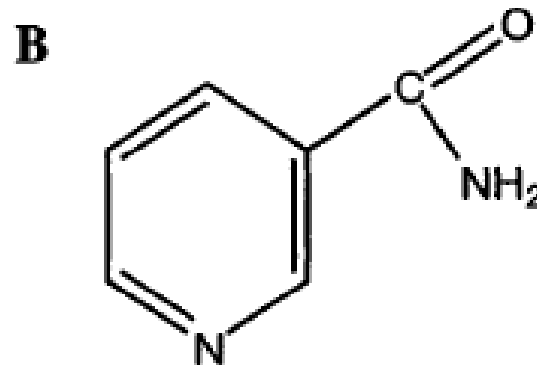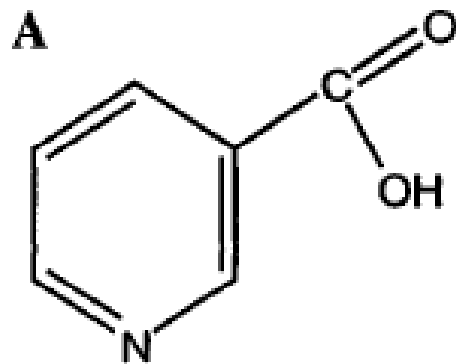
Structural Formulas of

(A) Nicotinic Acid and (B) Nicotinamide

- Niacin is also known as the pellagra preventive factor.
- Tryptophan can be converted by the body into niacin.
- When corn is treated with alkali or lime, the amount of available niacin can be greatly increased.
- Corn protein is low in tryptophan. The niacin of corn and other cereals may occur in a bound form called niacytin, that can be converted into niacin by alkali treatment.
- The human requirement of niacin is related to the intake of tryptophan.

Table 9–22 Niacin Content of Some Foods

| Product	Niacin (mg/100 g) Edible Portion
Barley (pearled)	3.1
Beans (green, snap)	0.5
Beans (white)	2.4
Beef (total edible)	4.4
Beef kidney	6.4
Beef liver	13.6
Chicken (dark meat)	5.2
Chicken (light meat)	10.7
Corn (field)	2.2
Haddock	3.0
Milk	0.1
Mushrooms	4.2
Peanuts	17.2
Peas	2.9
Potatoes	1.5
Spinach	0.6
Wheat	4.3
Yeast (dry)	36.7

The source of niacin

- Good dietary sources of this vitamin are liver, kidney, lean meat, chicken, fish, wheat, barley, rye, green peas, yeast, peanuts, and leafy vegetables.
- In animal tissues, the predominant form of niacin is the amide

The stability of niacin

- Niacin is probably the most stable of the B vitamins.
- It is unaffected by heat, light, oxygen, acid, or alkali.
- The main loss resulting from processing involves leaching into the process water.
- Blanching of vegetables may cause a loss of about 15 percent.
- Processing of milk, such as pasteurization, sterilization, evaporation, and drying have little or no effect on nicotinic acid level.
- In many foods, application of heat, such as roasting or baking, increases the amount of available niacin. This results from the change of bound niacin to the free form.

Vitamin B12 (Cyanocobalamine)

- This vitamin possesses the most complex structure of any of the vitamins and is unique in that it has a metallic element, cobalt, in the molecule.

- The molecule is a coordination complex built around a central tervalent cobalt atom and consists of two major parts—a complex cyclic structure that closely resembles the porphyrins and a nucleotide-like portion, 5,6-dimethyl-l-(α-D-ribofuranosyl) benzimidazole-3'-phosphate.
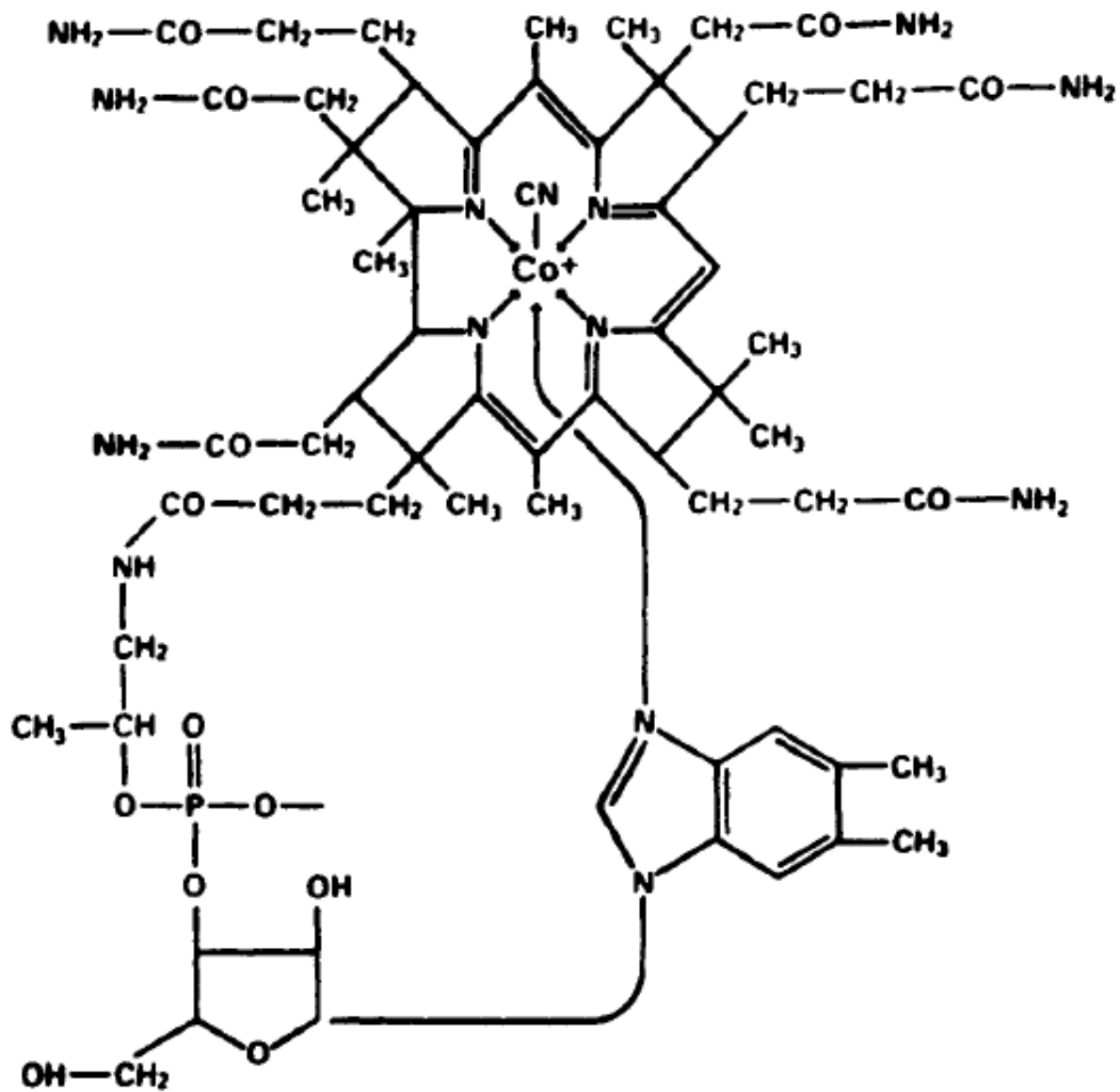
- Cyanocobalamine is a component of several coenzymes and has an effect on nucleic acid formation through its action in cycling 5-methyl-tetrahydrofolate back into the folate pool.
- The most important dietary sources of the vitamin are animal products. It is not surprising that vitamin B12 deficiency of dietary origin only occurs in vegetarians.
- Vitamin B12 is also produced by many microorganisms.

The source of vitamin B12

- In foods, the vitamin is bound to proteins via peptide linkages but can be readily absorbed in the intestinal tract.
- Few natural sources are rich in vitamin B12. However, only very small amounts are required in the diet.
- Good sources are lean meat, liver, kidney, fish, shellfish, and milk.
- In milk, the vitamin occurs as cobalamine bound to protein.

**Table 9–23** Vitamin B_{12} Content of Some Foods

Product	Vitamin B_{12}
Beef muscle	0.25–3.4 µg/100 g
Beef liver	14–152 µg/100 g
Milk	3.2–12.4 µg/L
Shellfish	600–970 µg/100 g (dry wt)
Egg yolk	0.28–1.556 µg/100 g

The stability of vitamin B12

- Vitamin B12 is not destroyed to a great extent by cooking, unless the food is boiled in alkaline solution.
- Pasteurization causes only a slight destruction of vitamin B12 in milk; losses range from 7 to 10 percent depending on pasteurization method. More drastic heat treatment results in higher losses.
- Boiling milk for two to five minutes causes a 30 percent loss, evaporation about 50 percent, and sterilization up to 87 percent.
- The loss in drying of milk is smaller; in the production of dried skim milk, the vitamin B12 loss is about 30 percent.

Folic Acid (Folacin)

● Folic acid is the main representative of a series of related compounds that contain three moieties: pterin, /7-aminobenzoic acid, and glutamic acid
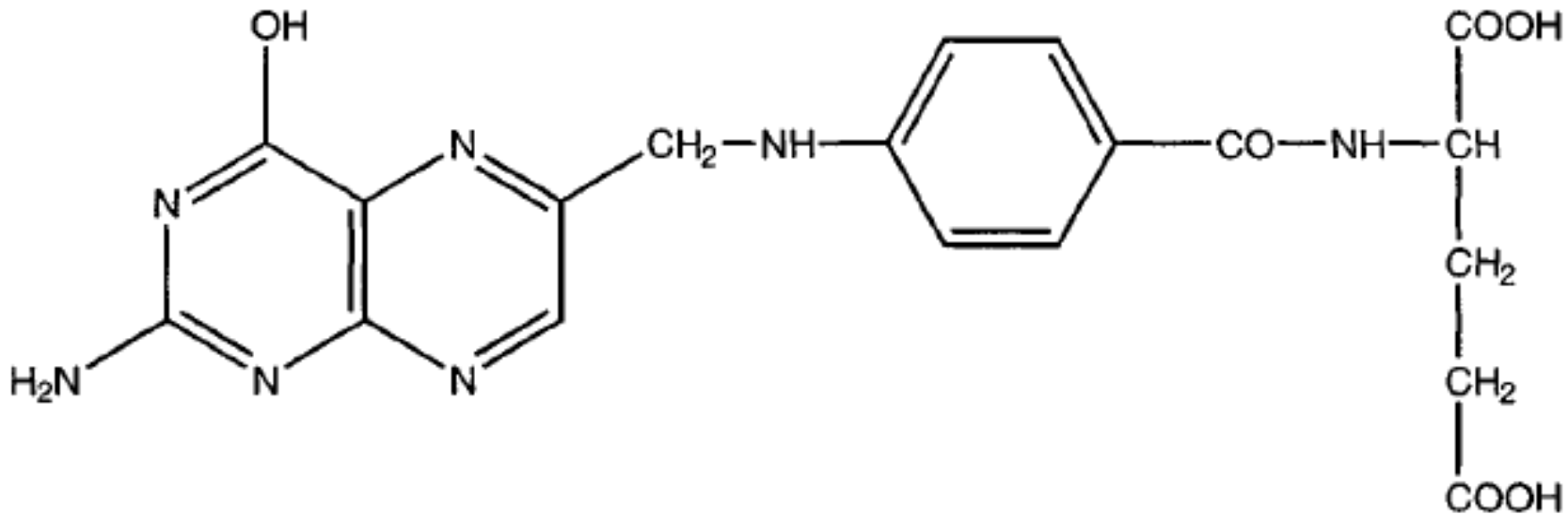
- The commercially available form contains one glutamic acid residue and is named pteroylglutamic acid (PGA).

- The naturally occurring forms are either PGA or conjugates with varying numbers of glutamic acid residues, such as tri- and heptaglutamates.

The source of folic acid

- The vitamin occurs in a variety of foods, especially in liver, fruit, leafy vegetables, and yeast.
- The usual form of the vitamin in these products is a polyglutamate.

Table 9–24 Folate Content of Some Foods

Product	Folate (μg/g)
Beef, boiled	0.03
Chicken, roasted	0.07
Cod, fried	0.16
Eggs, boiled	0.30
Brussels sprouts, boiled	0.20
Cabbage, boiled	0.11
Lettuce	2.00
Potato, boiled	0.12
Spinach, boiled	0.29
Tomato	0.18
Orange	0.45
Milk	0.0028
Bread, white	0.17
Bread, brown	0.38
Orange juice, frozen reconstituted	0.50
Tomato juice, canned	0.10

- The action of an enzyme (conjugase) is required to liberate the folic acid for metabolic activity; this takes place in the intestinal mucosa.
- The folacin of foods can be divided into two main groups on the basis of its availability to *L. casei:*

  (1) the so-called free folate, which is available to *L. casei* without conjugase treatment; and

  (2) the total folate, which also includes the conjugates that are not normally available to *L. casei.*

- About 25 percent of the dietary folacin occurs in free form.
- The folate in vegetables occurs mainly in the conjugated form; the folate in liver occurs in the free form.

The stability of folic acid

- Pasteurization and sterilization of milk involve only small losses or no loss.
- Boiling of milk causes no loss in folate; however, boiling of potato results in a 90 percent loss and boiling of cabbage a 98 percent loss.
- Reconstitution of dried milk followed by sterilization as can occur with baby formulas may lead to significant folacin losses.
- Fermentation of milk and milk products may result in greatly increased folate levels.

- Blanching of vegetables and cooking of meat do not appear to cause folic acid losses.

Table 9–25 Folic Acid Stability in Foods

Product	Treatment	Retention of Folic Acid	
		Free (%)	Total (%)
Cabbage	Boiled 5 min	32	54
Potatoes	Boiled 5 min	50	92
Rice	Boiled 15 min	—	10
Beef, pork, and chicken	Boiled 15 min	<50	<50
Various foods	Cooked	27	55

Source: From E. deRitter, Stability Characteristics of Vitamins in Processed Foods, *Food Technol.*, Vol. 30, pp. 48–51, 54, 1976.

Pantothenic Acid

- The free acid is very unstable and has the appearance of a hygroscopic oil. The calcium and sodium salts are more stable.

$$CH_2OH - C(CH_3)_2 - CHOH - CO - NH - CH_2 - CH_2 - R$$

Pantothenic acid: R = COOH; Panthenol: R = CH2OH.

- The calcium and sodium salts are more stable.
- The alcohol (panthenol) has the same biological activity as the acid.

- Only the dextrorotatory or D form of these compounds has biological activity.

- Pantothenic acid plays an important role as a component of coenzyme A, and this is the form in which it occurs in most foods.

The sources of pantothenic acid

- Pantothenic acid occurs in all living cells and tissues and is, therefore, found in most food products.

- In animal products, most of the pantothenic acid is present in the bound form, but in milk only about one-fourth of the vitamin is bound.

Table 9–26 Pantothenic Acid Content of Some Foods

Product	Pantothenic Acid ($\mu g/g$)
Beef, lean	10
Wheat	11
Potatoes	6.5
Split peas	20–22
Tomatoes	1
Orange	0.7
Walnuts	8
Milk	1.3–4.2
Beef liver	25–60
Eggs	8–48
Broccoli	46

The stability of pantothenic acid

- The vitamin is stable to air, and labile to dry heat.
- It is stable in solution in the pH range of 5 to 7 and less stable outside this range.
- Pasteurization and sterilization of milk result in very little or no loss.
- The production and storage of dried milk involves little or no loss of pantothenic acid.
- Cheese manufacture cause large losses during processing, but during ripening the pantothenic acid content increases, due to synthesis by microorganisms.

- Blanching of vegetables may involve losses of up to 30 percent.
- Boiling in water involves losses that depend on the amount of water used.

Biotin

- The structural formula of biotin contains three asymmetric carbon atoms, and eight different stereoisomers are possible.

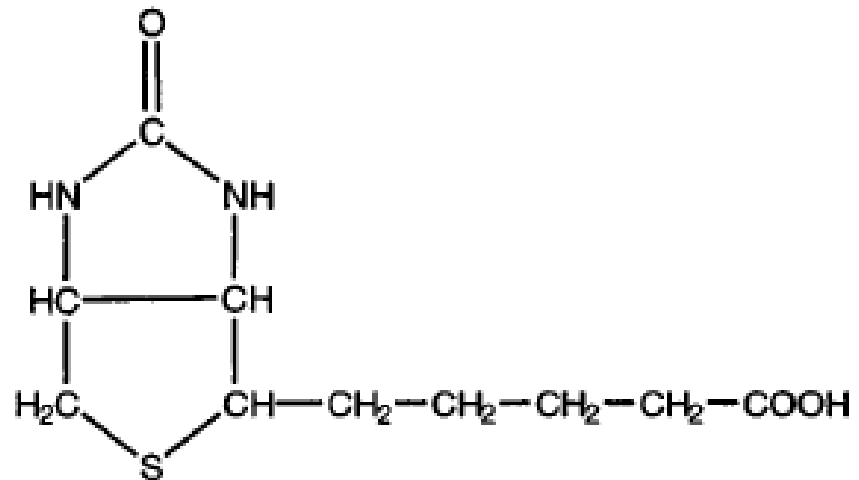- Only the dextrorotatory D-biotin occurs in nature and has biological activity.

Figure 9–23 Structural Formula of Biotin

The sources of biotin

Table 9–27 Biotin Content of Some Foods

Product	Biotin (μg/100 g)
Milk	1.1–3.7
Tomatoes	1
Broad beans	3
Cheese	1.1–7.6
Wheat	5.2
Beef	2.6
Beef liver	96
Lettuce	3.1
Mushrooms	16
Potatoes	0.6
Spinach	6.9
Apples	0.9
Oranges	1.9
Peanuts	34

- Biotin occurs in some products in free form (vegetables, milk, and fruits) and in other products is bound to protein (organ meats, seeds, and yeast).
- Good sources of the vitamin are meat, liver, kidney, milk, egg yolk, yeast, vegetables, and mushrooms.

- An important factor in biotin's availability is that some of the vitamin is derived from synthesis by intestinal microorganisms; this is demonstrated by the fact that three to six times more biotin is excreted in the urine than is ingested with the food.
- Biotin is deactivated by raw egg white. This is caused by the glycoprotein avidin. Heating of avidin will destroy the inactivator capacity for biotin.

The stability of biotin

- The vitamin appears to be quite stable.
- Heat treatment results in relatively small losses.
- The vitamin is stable to air and is stable at neutral and acid pH.
- Pasteurization and sterilization of milk result in losses of less than 10 percent.
- In the production of evaporated and dried milk, losses do not exceed 15 percent.

References

- deMan, J.M. 1999. The principles of food chemistry 3rd Ed. Aspen Publishers, Inc. Maryland.
- Henry,C. J. K & C. Chapman (Eds). 2002. The nutrition handbook for food processors. CRC Press. Boca Raton.