Vitamin B\textsubscript{12} Sources and Bioavailability

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The usual dietary sources of vitamin B\textsubscript{12} are animal foods, meat, milk, egg, fish, and shellfish. As the intrinsic factor-mediated intestinal absorption system is estimated to be saturated at about 1.5–2.0 \( \mu \text{g} \) per meal under physiologic conditions, vitamin B\textsubscript{12} bioavailability significantly decreases with increasing intake of vitamin B\textsubscript{12} per meal. The bioavailability of vitamin B\textsubscript{12} in healthy humans from fish meat, sheep meat, and chicken meat averaged 42\%, 56\%–89\%, and 61\%–66\%, respectively. Vitamin B\textsubscript{12} in eggs seems to be poorly absorbed (<9\%) relative to other animal food products. In the Dietary Reference Intakes in the United States and Japan, it is assumed that 50\% of dietary vitamin B\textsubscript{12} is absorbed by healthy adults with normal gastrointestinal function. Some plant foods, dried green and purple lavers (nori) contain substantial amounts of vitamin B\textsubscript{12}, although other edible algae contained none or only traces of vitamin B\textsubscript{12}. Most of the edible blue-green algae (cyanobacteria) used for human supplements predominately contain pseudovitamin B\textsubscript{12}, which is inactive in humans. The edible cyanobacteria are not suitable for use as vitamin B\textsubscript{12} sources, especially in vegans. Fortified breakfast cereals are a particularly valuable source of vitamin B\textsubscript{12} for vegans and elderly people. Production of some vitamin B\textsubscript{12}-enriched vegetables is also being devised.

Vitamin B\textsubscript{12} is the largest (molecular weight = 1355.4) and most complex of all the vitamins. Although the scientific use of the term "vitamin B\textsubscript{12}" is usually restricted to cyanocobalamin, vitamin B\textsubscript{12} represents all potentially biologically active cobalamins in this review. Cobalamin is the term used to refer to a group of cobalt-containing compounds (corrinoids) that have a lower axial ligand that contains the cobalt-coordinated nucleotide (5, 6-dimethylbenzimidazole as a base; Fig. 1). Cyanocobalamin, which is used in most supplements, is readily converted to the coenzyme forms of cobalamin (methylcobalamin and 5\'-deoxyadenosylcobalamin) in the human body (1).

Vitamin B\textsubscript{12} is synthesized only in certain bacteria (2). The vitamin B\textsubscript{12} synthesized by bacteria is concentrated mainly in the bodies of higher predatory organisms in the natural food chain system. Animal foods (i.e., meat, milk, egg, fish, and shellfish) but not plant foods are considered to be the major dietary sources of vitamin B\textsubscript{12} (1). Some plant foods, such as edible algae or blue-green algae (cyanobacteria), however, contain large amounts of vitamin B\textsubscript{12}. Vitamin B\textsubscript{12} compounds in algae appear to be inactive in mammals (3). Foods contain various vitamin B\textsubscript{12} compounds with different upper ligands; methylcobalamin and 5\'-deoxyadenosylcobalamin function, respectively, as coenzymes of methionine synthase (EC 2.1.1.13), which is involved in methionine biosynthesis and of methylmalonyl-CoA mutase (EC 5.4.99.2), which is involved in amino acid and odd-chain fatty acid metabolism in mammalian cells (4, 5).

Humans have a complex process for gastrointestinal absorption of dietary vitamin B\textsubscript{12} (6). Vitamin B\textsubscript{12} released from food protein is first bound to haptocorrin (salivary vitamin B\textsubscript{12}-binding protein) in the stomach. After proteolysis of haptocorrin–vitamin B\textsubscript{12} complex by pancreatic proteases in the duodenum, the released vitamin B\textsubscript{12} binds to intrinsic factor (IF, gastric vitamin B\textsubscript{12}-binding protein) in the proximal ileum. The IF–vitamin B\textsubscript{12} complex can enter mucosal cells in the distal ileum by receptor-mediated endocytosis. Bioavailability of dietary vitamin B\textsubscript{12} is significantly dependent on this gastrointestinal absorption.
In the Dietary Reference Intakes in the United States, it is assumed that 50% of dietary vitamin B₁₂ is absorbed by healthy adults (7); however, there are few data on the bioavailability of vitamin B₁₂ from foods. In this article presented here, up-to-date information is reviewed on vitamin B₁₂ content and bioavailability in various foods in relation to the prevention of vitamin B₁₂ deficiency.

Requirements of Vitamin B₁₂ and Vitamin B₁₂ Deficiency

The major signs of vitamin B₁₂ deficiency are megaloblastic anemia and neuropathy (7). Strict vegetarians (vegans) have a greater risk of developing vitamin B₁₂ deficiency relative to nonvegetarians (8) and must consume vitamin B₁₂–fortified foods or vitamin B₁₂–containing dietary supplements to prevent vitamin B₁₂ deficiency. A considerable proportion of elderly subjects having low serum vitamin B₁₂ levels without pernicious anemia have been reported to have malabsorption of protein-bound vitamin B₁₂ (food-bound vitamin B₁₂ malabsorption; Ref. 9). The food-bound vitamin B₁₂ malabsorption is found in patients with certain gastric dysfunctions, such as atrophic gastritis with decreased stomach acid secretion (10). Because the bioavailability of crystalline vitamin B₁₂ is not altered in patients with atrophic gastritis, the Institute of Medicine recommended that adults 51 years and older should obtain the majority of the recommended dietary allowance (RDA) of vitamin B₁₂ through the consumption of foods fortified with crystalline vitamin B₁₂ or vitamin B₁₂–containing supplements (7). Seal et al. (11) reported that a slightly higher dose (50 µg/day) of vitamin B₁₂ supplementation significantly increases serum vitamin B₁₂ concentrations in older patients with subnormal vitamin B₁₂ status.

The RDA of vitamin B₁₂ for adults is set at 2.4 µg/day in the United States (and Japan); however, daily body loss of the vitamin is estimated to be between 2 and 5 µg/day (7). Bor et al. (12) reported that a daily vitamin B₁₂ intake of 6 µg appears to be sufficient to maintain a steady-state concentration of plasma vitamin B₁₂ and vitamin B₁₂–related metabolic markers.

Assay of Vitamin B₁₂ in Foods

Historically, vitamin B₁₂ content of foods has been determined by bioassay with certain vitamin B₁₂–requiring microorganisms, such as Lactobacillus delbrueckii subsp. lactis ATCC7830 (formerly Lactobacillus leichmannii; Ref. 13). Radioisotope dilution assay (RIDA) method with radiolabeled vitamin B₁₂ and hog IF (the most specific vitamin B₁₂–binding protein) has also been used for the determination of vitamin B₁₂ content in foods (14). Although it was reported that the values determined by the RIDA method were slightly higher in human serum than those determined by the microbiologic method (15), Casey et al. (14) demonstrated the excellent correlation between both methods in food vitamin B₁₂ analysis.

A fully automated chemiluminescence vitamin B₁₂ analyzer with the acridinium ester–labeled vitamin B₁₂ derivative and IF has been commercialized. Currently, various types of similar vitamin B₁₂ analyzers are being...
manufactured and clinically used for the routine assay of human serum vitamin B\textsubscript{12} worldwide. About 10 years ago, my colleagues and I evaluated the applicability of this machine in food analysis, indicating the excellent correlation coefficient between both methods in most foods tested, although in some specific foods the values determined by the microbiologic method were about several-fold greater than the values determined by the chemiluminescence method (16). This difference may be due to the fact that \textit{L. delbrueckii} used for the microbiologic assay of food vitamin B\textsubscript{12} uses corrinoid compounds that are inactive for humans as well as vitamin B\textsubscript{12}. Ball (1) stated that about 30\% of the reported vitamin B\textsubscript{12} in foods may be microbiologically active corrinoids rather than vitamin B\textsubscript{12}. Furthermore, it is known that both deoxyribosides and deoxynucleotides (known as the alkali-resistant factor) can substitute vitamin B\textsubscript{12} in this lactic bacterium (17).

**Vitamin B\textsubscript{12} in Animal Food**

**Meat.** In the United States Department of Agriculture database, vitamin B\textsubscript{12} contents of cooked beef liver, lean meat, and turkey are estimated to be 83, 3, and 33 \mu g/100 g, respectively (18). Appreciable losses (~33\%) of vitamin B\textsubscript{12} in meats by cooking have been reported (19, 20).

Bioavailability of vitamin B\textsubscript{12} from 100 g (0.9 \mu g vitamin B\textsubscript{12}), 200 g (3.0 \mu g), and 300 g (5.1 \mu g) of ground patties cooked from mutton (labeled with radioactive vitamin B\textsubscript{12}) in normal human subjects averaged 56\%–77\%, 76\%–89\%, and 40\%–63\%, respectively (21). An average absorption of vitamin B\textsubscript{12} from liver pâté (38 \mu g vitamin B\textsubscript{12}) is approximately 10\%. Since the IF-mediated intestinal absorption system is estimated to be saturated at about 1.5–2.0 \mu g per meal under the physiologic conditions (22), vitamin B\textsubscript{12} bioavailability should decrease significantly with increases in the intake of vitamin B\textsubscript{12} per meal.

Absorption of vitamin B\textsubscript{12}, assessed by measuring fecal excretion of radioactivity, after consuming 100 g (0.4–0.6 \mu g vitamin B\textsubscript{12}), 200 g (0.8–1.3 \mu g), and 300 g (1.3–1.9 \mu g) of chicken meat (labeled with radioactive vitamin B\textsubscript{12}) in healthy human subjects averaged 65\%, 63\%, and 61\%, respectively (23).

**Milk.** Although vitamin B\textsubscript{12} content (0.3–0.4 \mu g/100 g) of various types of milk is not high (18), milk and dairy products are significant contributors of vitamin B\textsubscript{12} intakes, since the intake of dairy products is high in the general population (7). In bovine milk, all naturally occurring vitamin B\textsubscript{12} is bound to the transcobalamin, one of the mammalian vitamin B\textsubscript{12}–binding proteins (24). When radioactive vitamin B\textsubscript{12} (0.25 \mu g) mixed in water or milk was administered to human subjects, the mean absorption, as assessed by a whole-body counting of radioactivity, was 55\% or 65\%, respectively (25).

Appreciable losses of vitamin B\textsubscript{12} have been reported during the processing of milk; boiling for 2–5 min and 30 min resulted in 30\% and 50\% loss, respectively (1, 20). The 5-min microwave cooking led to 50\% loss and 5\%–10\% lost by pasteurization (1, 20). When various milk samples were exposed to fluorescent light for 24 hrs at 4°C, the vitamin B\textsubscript{12} concentration decreased considerably, depending on the type of milk tested (26). On the other hand, when the pasteurized milk was refrigerated for 9 days under retail-simulating or domestic handling conditions, there was no appreciable decline in the concentration of milk vitamin B\textsubscript{12} (27).

Vitamin B\textsubscript{12} concentrations in fermented milk decreased significantly during storage at 4°C for 14 days relative to the original milk. About 20\%–60\% of vitamin B\textsubscript{12} that is originally presented in milk is recovered in cottage cheese, hard cheese, and blue cheese (28). Sato \textit{et al.} (29) demonstrated that the content of vitamin B\textsubscript{12} in the whey is reduced considerably during lactic acid fermentation. This decrease in vitamin B\textsubscript{12} content in whey is due to the production of vitamin B\textsubscript{12} compounds that are not easily extracted for detection by conventional extraction method. Although the vitamin B\textsubscript{12} compounds could be extracted by sonication and treatment by proteases, such as pepsin and papain, no information is available on any chemical properties of these compounds (29).

**Egg.** Vitamin B\textsubscript{12} content in the whole egg is about 0.9–1.4 \mu g/100 g (18, 30), and most of the vitamin B\textsubscript{12} is found in the egg yolk (31). Vitamin B\textsubscript{12} intakes from the egg are generally large, because it is a popular food item (7). Bioavailability of vitamin B\textsubscript{12} from scrambled egg yolks, scrambled whole eggs, boiled eggs, and fried eggs (1.1–1.4 \mu g vitamin B\textsubscript{12} per 100 g) averaged 8.2\%, 3.7\%, 8.9\%, and 9.2\%, respectively (30). Vitamin B\textsubscript{12} in eggs is generally poorly absorbed relative to other animal food products (32).

**Shellfish.** Various shellfish are consumed widely. The shellfish that siphon large quantities of vitamin B\textsubscript{12}–synthesizing microorganisms in the sea are known to be excellent sources of vitamin B\textsubscript{12}, of which concentrations can exceed sometimes 10 \mu g/100 g (33). The vitamin B\textsubscript{12}–synthesizing microorganisms can also synthesize various corrinoids (including corrinoid compounds inactive for humans) with different bases in the lower ligand. When corrinoid compounds were isolated and characterized in popular shellfish, such as oysters, mussels, and short-necked clams, each corrinoid compound was identified as vitamin B\textsubscript{12} (34). The higher values in the determination of vitamin B\textsubscript{12} by the microbiologic method compared with the chemiluminescence method may be due to occurrence of certain vitamin B\textsubscript{12}–substitutive compounds, of which chemical properties have not been characterized.

**Fish.** Fish (or shellfish) contribute greatly to vitamin B\textsubscript{12} intake among Asians, particularly Japanese people, and this trend is spreading throughout the world (35). In the USDA database, vitamin B\textsubscript{12} contents of certain fish (salmon, sardine, trout, tuna, etc.) are 3.0 to 8.9 \mu g/100 g (18). Based on our studies, the dark muscle of skipjack contains a substantial amount (159 \mu g/100 g) of vitamin B\textsubscript{12} compared with the light muscle (dorsal portion 10 \mu g/100 g;
ventral portion 8 μg/100 g; Ref. 36). When a corrinoid compound was isolated and characterized in the dark muscle, it was identified as vitamin B₁₂. Similar results of high vitamin B₁₂ content in dark muscle were found in the yellowfin tuna (37).

Various commercially available soup stocks, which are mainly made of dried bonito shavings and dried sardines, contain considerable amounts (0.2 to 1.2 μg/100 ml) of free vitamin B₁₂, indicating that these may be excellent free vitamin B₁₂ sources (38). The loss of vitamin B₁₂ from fish meat by various cooking methods (boiling, steaming, sautéing, frying, and microwaving) was not high, with a range of 2.3%–14.8% (36).

Doscherholmen et al. (38) measured the bioavailability of radioactive vitamin B₁₂ that was injected into the rainbow trout. A few weeks after this injection, the bioavailability of vitamin B₁₂ from the fish meat was evaluated. The bioavailabilities of labeled vitamin B₁₂ in 50 g (equivalent to 2.1 μg vitamin B₁₂), 100 g (4.1 μg), 200 g (9.2 μg), and 300 g (13.3 μg) of fish meat were 42%, 38%, 42%, and 30%, respectively.

Salted and Fermented Fish. The highest amount of vitamin B₁₂ among foods described in the Japanese Standard Tables of Food Composition is 328 μg/100 g in salted and fermented salmon kidney that is called “Mefun” (39). Eating only 0.8 g Mefun can supply the total RDA (2.4 μg/day) for the adult population. Although this item has a delicate flavor, it has an extremely limited application, since it is popular only in Japan. It might be interesting, however, to describe the characterization of vitamin B₁₂ in this item, which may potentially have the highest vitamin B₁₂ content in nature. The vitamin B₁₂ found in Mefun is not derived from concomitant vitamin B₁₂–synthesizing bacteria, but is accumulated in the salmon kidney. The majority of vitamin B₁₂ found in Mefun was recovered in the free vitamin B₁₂ fractions (40). Mefun may be an excellent free vitamin B₁₂ source for elderly subjects with food-bound vitamin B₁₂ malabsorption.

Fish Sauce. Various kinds of fish sauces, traditional food supplements in the diet, are widely used as a seasoning worldwide. Fish sauce (Nam-pla) appears to constitute a major source of vitamin B₁₂ in Thailand, since it contains considerable amounts of vitamin B₁₂ (41). A considerable amount of vitamin B₁₂ (range: 2.3 to 5.5 μg/100 g) was also found in “Ishiru” (a Japanese traditional fish sauce; Ref. 42). When two corrinoid compounds in the fish sauce were isolated and characterized, the main compound was identified as vitamin B₁₂, but the other minor compound could not be identified (42). Corrinoid compounds found in various fish sauces made in Japan could not be identified (43). Fish sauce may not be suitable for use as a source of vitamin B₁₂, considering the low daily intake of the sauce and occurrence of the unidentified corrinoid compounds.

Vitamin B₁₂ in Plant Food

Vegetables. Many studies have been performed to measure vitamin B₁₂ content in various vegetables. For decades, edible bamboo shoots have been believed to contain considerable amounts of vitamin B₁₂. However, it turned out that they do not contain appreciable amounts of vitamin B₁₂; however, certain compounds showing vitamin B₁₂–like activity (known as the alkali-resistant factor) were found in them (44). Similar results were found in cabbage, spinach, celery, garlic chrysanthemum, lily bulb, and taro (44). Only trace amounts of vitamin B₁₂ (<0.1 μg/100 g of wet weight edible portion), which was estimated by subtracting the alkali-resistant factor from total vitamin B₁₂, were found in brocoli, asparagus, Japanese butterbur, mung bean sprouts, tassa jute, and water shield (44). These vegetables may have the ability to take up vitamin B₁₂ found in certain organic fertilizer.

Mozafar (45) demonstrated that the addition of an organic fertilizer, cow manure, significantly increases the vitamin B₁₂ content in barley kernels and spinach leaves. Mozafar and Oefii (46) investigated uptake of vitamin B₁₂ by soybean roots under water culture conditions. Sato et al. (47) reported that a high level of vitamin B₁₂ is incorporated into a vegetable, kawiare daikon (radish sprout), by soaking its seeds in vitamin B₁₂ solutions before germination. The amount of vitamin B₁₂ incorporated into kawiare daikon increases up to about 170 μg/100 g of wet sprout with 3-hr soaking of seeds in 200 μg/ml vitamin B₁₂ solution. These vitamin B₁₂–enriched vegetables may be of special benefit to vegans or elderly persons with food-bound vitamin B₁₂ malabsorption.

Tea Leaves and Tea Drinks. Considerable amounts of vitamin B₁₂ are found in various types of tea leaves: green (0.1–0.5 μg vitamin B₁₂ per 100 g dry weight), blue (about 0.5 μg), red (about 0.7 μg), and black (0.3–1.2 μg) tea leaves (48).

When a corrinoid compound was isolated from Japanese fermented black tea (Batabata-cha), the compound was identified as vitamin B₁₂ (49). When vitamin B₁₂–deficient rats were fed this tea drink (50 ml/day, equivalent to a daily dose of 1 ng vitamin B₁₂) for 6 weeks, urinary methylmalonic acid excretion (an index of vitamin B₁₂ deficiency) of the tea drink–supplemented rats decreased significantly compared with that of the deficient rats (49). These results indicate that the vitamin B₁₂ found in the fermented black tea is bioavailable in rats. However, only 1–2 liters of consumption of fermented tea drink (typical regular consumption in Japan), which is equivalent to 20–40 ng vitamin B₁₂, is not sufficient to meet the RDA of 2.4 μg/day for adult humans.

Soybean. Vitamin B₁₂ contents of soybean are low or undetectable. A soybean-fermented food, tempe, contains a large amount of vitamin B₁₂ (0.7 to 8 μg/100 g; Ref. 50). Certain bacteria contamination during the process of tempe production may contribute to the vitamin B₁₂ increase of

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1Nishioka M, Miyamoto E, and Watanabe F. Unpublished data.

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tempe (51). Another fermented soybean, natto, contains a minute amount of vitamin B$_{12}$ (0.1 to 1.5 μg/100 g; Ref. 52).

**Edible Algae.** Various types of edible algae are used for human consumption the world over. Dried green (*Enteromorpha* sp.) and purple (*Porphyra* sp.) lavers (nori) are the most widely consumed among the edible algae and contain substantial amounts of vitamin B$_{12}$ (32 to 78 μg/100 g dry weight; Ref. 39). In Japanese cooking, several sheets of nori (9 × 3 cm; about 0.3 g each) are often served for breakfast. A large amount of nori (≪6 g) can be consumed from certain sushi, vinegared rice rolled in nori. However, edible algae other than these two species contain none or only traces of vitamin B$_{12}$ (39). Dagnelie *et al.* (53) reported the effect of edible algae on the hematologic status of vitamin B$_{12}$–deficient children, suggesting that algal vitamin B$_{12}$ appears to be nonbioavailable. As bioavailability of the algal vitamin B$_{12}$ is not clear in humans, my colleagues and I characterized corrinoid compounds to determine whether the dried purple and green lavers and eukaryotic microalgae (*Chlorella* sp. and *Pleurochrysis carterae*) used for human food supplements contain vitamin B$_{12}$ or inactive corrinoids. My colleagues and I found that these edible algae contain a large amount of vitamin B$_{12}$ without the presence of inactive corrinoids (54–57).

To measure the bioavailability of vitamin B$_{12}$ in the lyophilized purple laver (*Porphyra yezoensis*), the effects of feeding the laver on various parameters of vitamin B$_{12}$ were investigated in vitamin B$_{12}$–deficient rats (58). Within 20 days after vitamin B$_{12}$–deficient rats were fed a diet supplemented with dried purple laver (10 μg vitamin B$_{12}$/kg diet), urinary methylmalonic acid excretion became undetectable and hepatic vitamin B$_{12}$ (especially coenzyme vitamin B$_{12}$) levels significantly increased. These results indicate that vitamin B$_{12}$ from the purple lavers is bioavailable in rats.

A nutritional analysis for the dietary food intake and serum vitamin B$_{12}$ level of a group of six vegan children aged 7 to 14 who had been living on a vegan diet including brown rice for 4 to 10 years suggests that consumption of nori may keep vegans from suffering vitamin B$_{12}$ deficiency (59). Rauma *et al.* (60) also reported that vegans consuming nori and/or chlorella had a serum vitamin B$_{12}$ concentration twice as high as those not consuming these algae.

**Edible Cyanobacteria.** Some species of the cyanobacteria, including *Spirulina*, *Aphanizomenon*, and *Nostoc*, are produced at annual rates of 500-3000 tons for food and pharmaceutical industries worldwide (61). Tablets containing *Spirulina* sp. are sold as a health food food, since it is known to contain a large amount of vitamin B$_{12}$ (62). We found that commercially available spirulina tablets contained 127–244 μg vitamin B$_{12}$ per 100 g weight (63). When two corrinoid compounds were characterized from the spirulina tablets, the major (83%) and minor (17%) compounds were identified as pseudovitamin B$_{12}$ (adeninly cobamide) and vitamin B$_{12}$, respectively (Fig. 2). Several groups of investigators indicated that pseudovitamin B$_{12}$ is hardly absorbed in mammalian intestine with a low affinity to IF (64, 65). Furthermore, researchers showed that spirulina vitamin B$_{12}$ may not be bioavailable in mammals (63, 66). Herbert (67) reported that an extract of spirulina contains two vitamin B$_{12}$ compounds that can block the metabolism of vitamin B$_{12}$. And van den Berg *et al.* (68) demonstrated that a spirulina-supplemented diet does not induce severe vitamin B$_{12}$ deficiency in rats, implying that the feeding of spirulina may not interfere with the vitamin B$_{12}$ metabolism. Further studies are needed to clarify bioavailability of spirulina vitamin B$_{12}$ in humans.

*Aphanizomenon flos-aquae*, a fresh water cyanobacterium, grow naturally in Upper Klamath Lake, Oregon. Kay (69) described that the bacterial cells contain some corrinoid compounds that can be used as vitamin B$_{12}$ in humans. In contrast, my colleagues and I found that the corrinoid compound purified from *Aphanizomenon* cells was identified as pseudovitamin B$_{12}$, which is inactive corrinoid for humans (70). We found that the dried bacterial cells contained 616 μg vitamin B$_{12}$ per 100 g weight. *Escherichia coli* 215-bioautography of the *Aphanizomenon* extract indicated that the bacterial cells contained only pseudovitamin B$_{12}$ (70).

*Aphanathece sacrum* (Suizenji-nori) is an edible cyanobacterium that is indigenous to Japan. The dried bacterial cells are used as an ordinary food item after soaking in water or a nutritional supplement. The nutrition labeling of this bacterial product shows that the dried cells contain a large amount of vitamin B$_{12}$ (94 μg/100 g), whereas, the corrinoid compound purified from the bacterial cells was identified as pseudovitamin B$_{12}$ (71). Therefore, its nutritional value is questionable. *Nostoc commune* (Ishikurage) contains considerable amounts (99 μg/100 g) of vitamin B$_{12}$ in its dried cells as measured by the microbiologic method; however, only 12% of the vitamin may be active, since the main (88%) and minor (12%) compounds in the bacterial cells were identified as pseudovitamin B$_{12}$ and vitamin B$_{12}$, respectively (72). In summary, the results reviewed above indicate that edible cyanobacteria often contain a large amount of pseudovitamin B$_{12}$, which is known to be biologically inactive in humans. Therefore, they are not suitable for use as a source of vitamin B$_{12}$ for the prevention of vitamin B$_{12}$ deficiency among the high-risk population, such as vegans and elderly subjects.

**Vitamin B$_{12}$–Fortified Cereals.** Ready-to-eat cereals fortified with vitamin B$_{12}$ are known to constitute a great proportion of dietary vitamin B$_{12}$ intake in the United States (7). Several groups of investigators suggested that eating a breakfast cereal fortified with folic acid, vitamin B$_{12}$, and vitamin B$_{6}$ increases blood concentrations of these vitamins and decreases plasma total homocysteine concentrations in elderly populations (73). Fortified breakfast cereals have become a particularly valuable source of vitamin B$_{12}$ for vegetarians and elderly people.
Conclusion

Vitamin B$_{12}$ contents determined by the microbiologic assay method used widely in food analysis are incorrect in some specific foods, because this lactic bacterium can utilize inactive corrinoid compounds, such as pseudovitamin B$_{12}$, and substitute both deoxyribosides and deoxynucleotides (known as the alkali-resistant factor) for vitamin B$_{12}$. Thus, vitamin B$_{12}$ contents should be calculated by subtracting the intake of <2 µg vitamin B$_{12}$ per meal in healthy humans.

Table 1. Bioavailability of Dietary Vitamin B$_{12}$

<table>
<thead>
<tr>
<th>Foods</th>
<th>Predominate corrinoid$^b$</th>
<th>Bioavailability$^c$</th>
<th>Content (µg/100 g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal meats</td>
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<tr>
<td>Mutton, cooked</td>
<td></td>
<td>56%–89% (21)</td>
<td>2.6 (18)</td>
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<td>Chicken, cooked</td>
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<td>61%–66% (23)</td>
<td>9.4 (18)</td>
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<td>Cow’s milk</td>
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<td>65% (25)</td>
<td>0.4 (18)</td>
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<td>Eggs</td>
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<tr>
<td>Chicken, cooked</td>
<td></td>
<td>&lt;9% (31)</td>
<td>1.3 (18)</td>
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<tr>
<td>Shellfish</td>
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<tr>
<td>Oyster</td>
<td>Vitamin B$_{12}$ (34)</td>
<td></td>
<td>46.3 (34), 28.1 (17)</td>
</tr>
<tr>
<td>Mussel</td>
<td>Vitamin B$_{12}$ (34)</td>
<td></td>
<td>15.7 (34), 10.3 (17)</td>
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<tr>
<td>Short-necked clam</td>
<td>Vitamin B$_{12}$ (34)</td>
<td></td>
<td>37.0 (34), 52.4 (17)</td>
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<td>Fish meats</td>
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<tr>
<td>Skipjack, dark muscle</td>
<td>Vitamin B$_{12}$ (36)</td>
<td></td>
<td>158.5 (36)</td>
</tr>
<tr>
<td>Yellowfin tuna, dark muscle</td>
<td>Vitamin B$_{12}$ (37)</td>
<td></td>
<td>52.9 (37)</td>
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<td>Rainbow trout, cooked</td>
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<td>42.0% (38)</td>
<td>4.9 (18)</td>
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<td>Edible algae</td>
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<td>Purple laver</td>
<td>Vitamin B$_{12}$ (54)</td>
<td></td>
<td>32.3 (54), 77.6 (17)</td>
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<td>Green laver</td>
<td>Vitamin B$_{12}$ (55)</td>
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<td>63.6 (55), 31.8 (17)</td>
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<tr>
<td>Chlorella</td>
<td>Vitamin B$_{12}$ (56)</td>
<td></td>
<td>200.9–211.6 (56)</td>
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</table>

$^a$ Numbers in parentheses are reference numbers.

$^b$ Isolated and identified.

$^c$ Intake of <2 µg vitamin B$_{12}$ per meal in healthy humans.
values of the alkali-resistant factor from the values of total (or apparent) vitamin B\textsubscript{12} in all foods tested to prevent overestimating their vitamin B\textsubscript{12} contents. Even if IF-based clinical assay kits or analyzers are used for measuring food vitamin B\textsubscript{12} content, they may not represent only vitamin B\textsubscript{12} because of the possibility that the binding of vitamin B\textsubscript{12} to IF is interfered slightly by certain food ingredients or inactive corrinoid compounds, such as pseudovitamin B\textsubscript{12}. The difficulty to evaluate whether certain foods contain vitamin B\textsubscript{12} or inactive corrinoids may be easily resolved by the use of a simple technique, bioautography with vitamin B\textsubscript{12}-dependent \textit{E. coli} 215 after separation of the sample by silica gel 60 thin-layer chromatography (72, 74). The database of vitamin B\textsubscript{12} content in foods should be revised in order to accurately assess dietary intakes of vitamin B\textsubscript{12}.

Although food items that contribute to the vitamin B\textsubscript{12} intake vary widely depending on food cultures or food habits throughout the world, animal products (meat, milk, egg, fish, and shellfish) are excellent sources of vitamin B\textsubscript{12} (Table 1). Dried edible cyanobacteria as nutritional supplements may not be suitable for vitamin B\textsubscript{12} sources, because the majority of the vitamin in the bacterial cells is pseudovitamin B\textsubscript{12}. As technologies advance, various plant foods that contain an appreciable amount of naturally occurring vitamin B\textsubscript{12} and are fortified with crystalline vitamin B\textsubscript{12} may be available for human consumption to maintain adequate vitamin B\textsubscript{12} status in the general population and to prevent vitamin B\textsubscript{12} deficiency among vegans or elderly persons.

For the Dietary Reference Intakes in the United States and Japan, it is assumed that 50% of dietary vitamin B\textsubscript{12} is absorbed and utilized by healthy adults with a normal gastrointestinal function. Further information on bioavailability of vitamin B\textsubscript{12} from various food sources of vitamin B\textsubscript{12} is needed to determine more precise RDA of the vitamin.

12. Bor MV, Lydeking-Olesen E, Møller J, Nexø E. A daily intake of approximately 6 \textmu g vitamin B\textsubscript{12} appears to saturate all the vitamin B\textsubscript{12}-related variables in Danish postmenopausal women. Am J Clin Nutr 83:52–58, 2006.


