Special Article

Vitamin B_{12} in meat and dairy products

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Vitamin B_{12} is synthesized exclusively by microorganisms; therefore, humans must absorb it from food. Excellent sources of B_{12} are foods of ruminant origin, so dairy and meat products play an important role in efforts to meet the official daily B_{12} intake recommendation of 3.0 μg. Concentrations of the vitamin vary within foods of ruminant origin, with the highest concentrations found in offal such as liver and kidney. In comparison, dairy products have much lower quantities of the vitamin. In bovine milk, the B_{12} concentration is stable with regard to breed, feed, season, and stage of lactation, but in ruminant meat, the amount of B_{12} can vary based on the feeding and husbandry of the animal as well as the cut of meat chosen and its preparation. Processing of ruminant food, including thermal treatment, usually diminishes the vitamin B_{12} concentration. This review summarizes the vitamin B_{12} content of foods and discusses the impact of food processing on vitamin content. The contribution of ruminant food sources to B_{12} intake is specifically evaluated, with its bioavailability taken into account.

INTRODUCTION

Vitamin B_{12} (also known as cobalamin) is a chemical compound with vitamin properties. It consists of cobalt as the central atom and a corrin ring that encloses the metal atom. In comparison with other B vitamins, B_{12} is not synthesized by animals, fungi, or plants. Exclusively, microorganisms (mainly anaerobes) or archaebacteria in the presence of cobalt are able to produce vitamin B_{12}. The most frequently occurring natural and active forms of B_{12} are adenosylcobalamin (also known as coenzyme B_{12}) and methylcobalamin.[1] Hydroxocobalamin and industrially produced cyanocobalamin are inactive forms of vitamin B_{12} that need to be metabolized in order to be used by humans.[2]

Although the intestinal flora of humans is able to synthesize vitamin B_{12}, humans are not able to absorb it since the location of synthesis (the colon) is too distal from the location of absorption (the small intestine).[3] Therefore, vitamin B_{12} has to be consumed through food. Foods of ruminant origin are an important source of vitamin B_{12} due to the production of cobalamin by bacteria inhabiting the gastrointestinal tract of ruminants. After biosynthesis, the vitamin is stored in the muscles and the liver of the animal or secreted via the animal's milk.[4] Humans can benefit from these stores by consuming ruminant meat and milk. Daily intake of these foods helps humans meet the recommended daily amount of vitamin B_{12} (3.0 μg/day).[5] However, vegetarians and vegans who restrict or eliminate consumption of animal-source foods are at higher risk for developing a B_{12} deficiency.[6]

In light of recommendations to limit red meat intake and the rising popularity of vegetarian and vegan lifestyles, it is worthwhile to examine both the concentrations and bioavailability of vitamin B_{12} in animal-based meat and milk as well as to quantify the contributions these products make to daily intake of B_{12}. The present article provides an overview of the vitamin B_{12} supply from meat and dairy products, with a particular focus on its concentration in and bioavailability from ruminant foods as well as the contributions these sources make to daily intake. The impact of food processing is additionally documented.

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VITAMIN B_{12} METABOLISM AND BIOLOGICAL FUNCTIONS

Cobalamins are considered to be the most complex cofactors in nature.[1] In food, their most important representative, vitamin B_{12}, is bound to proteins known as R-proteins or R-binders. Different steps and conditions are necessary for the effective uptake of cobalamin, including adequate synthesis of hydrochloric acid, proteases, and intrinsic factor (IF).[2] First, vitamin B_{12} is released from food proteins by means of the proteolytic enzyme pepsin. This enzyme is secreted as pepsinogen in the stomach and activated by hydrochloric acid. Subsequently, the vitamin binds to the glycoprotein haptocorrin, which is secreted with saliva. In the small intestine, pancreatic proteases break down the B_{12}–haptocorrin bonds, thus enabling formation of the B_{12}–IF complex (B_{12}–IF).[7] In a subsequent step, B_{12}–IF enters the apical surface of the cells of the distal ileum by binding to a specific receptor, cubilin, and it passes through the cells by being incorporated into cellular lysosomes.[8] After entering the cell, B_{12} is released from the IF. For further transport, cobalamin binds to another protein, either to haptocorrin, which is responsible for the transport of B_{12} to the liver, or to transcobalamin, which builds a complex with vitamin B_{12}, holotranscobalamin (the active form of B_{12}). Holotranscobalamin is the only active B_{12} fraction that can be incorporated into tissue cells.[9]

Another mechanism of cobalamin absorption occurs in the presence of large amounts of vitamin B_{12}, e.g., after ingestion of vitamin B_{12} supplements. Approximately $\leq$1% of free cobalamin can be absorbed by diffusion into the cells of the epithelial ileum.[2] Most unused vitamin B_{12} is stored in the liver and muscles and has a half-life of 1–4 years.[10]

Vitamin B_{12} combines major biological functions, i.e., methylcobalamin acts as an important carrier of methyl groups and as such it is, as co-factor of the enzyme methionine synthase, involved in the transformation of homocysteine to the metabolite methionine in the cytosol.[11] These processes and subsequent metabolic reactions are involved in the synthesis of neurotransmitters, phospholipids, DNA, and RNA.[10] Adenosylcobalamin acts as a cofactor of methylmalonyl-coenzyme A (CoA) mutase, which converts methylmalonyl-CoA to succinyl-CoA in the mitochondria. This reaction is involved in the catabolism of cholesterol, fatty acids, and several amino acids.[12]

VITAMIN B_{12} REQUIREMENTS AND B_{12} DEFICIENCY

Vitamin B_{12} status in humans depends on intake.[13–15] It is assumed that adults have a total cobalamin content of 2–3 mg.[16] A pooled analysis showed that 1.4–5.1 µg of vitamin B_{12} are excreted every day.[17] In developed countries, B_{12} intake is normally adequate. Nevertheless, B_{12} deficiency is the most common vitamin deficiency requiring clinical therapy.[3] There are a variety of causes of deficiency, including congenital disturbances of cobalamin metabolism and impairment of absorption, which can be caused by defects of the gastric mucosa, chronic atrophic gastritis, gastrectomy, malabsorption in the ileum, intestinal stasis, drugs, and intestinal parasites. Other causes include old age and pernicious anemia, which is characterized by autoimmune destruction of gastric parietal cells resulting in a lack of IF.[3,18] In developing countries, B_{12} deficiency is common because of typically low consumption of animal foods, resulting in inadequate intakes.[19] Worldwide, vegans and vegetarians may suffer from cobalamin deficiency due to their avoidance of B_{12}-containing foods.[6] Newborns may also suffer from B_{12} deficiency when their mothers suffer from the same deficiency.[3]

The main syndrome of vitamin B_{12} deficiency is pernicious anemia, which is characterized by two primary symptoms: megaloblastic anemia and/or neuropathy. Megaloblastic anemia can be accompanied by anemia, enlarged red blood cells, hypersegmented neutrophil leucocytes, low white blood cell count, low platelet count, a sore tongue, and infertility. Neuropathy symptoms are characterized by degeneration of the spinal cord, loss of proprioceptive sensation, spastic weakness in the lower limbs, and, in some instances, depression or memory loss. However, the onset of B_{12} deficiency is gradual due to large stores in the body. In the first instance, a subclinical deficiency is defined by a low level of serum B_{12} and/or a raised methylmalonate concentration, followed by the less common clinical deficiency (megaloblastic anemia/neuropathy).[18]

In the United States, the recommended daily allowance of vitamin B_{12} for females and males between the ages of 13 and >70 years is 2.4 µg/day.[16] The nutrition societies of Germany, Switzerland, and Austria recommend a slightly higher dose of 3.0 µg/day[5] (Table 1). However, some research findings suggest that even higher daily intake levels, in the range of 3.8–20.7 µg, are necessary to cover daily B_{12} losses.[17]

VITAMIN B_{12} CONTENT OF MEAT AND DAIRY PRODUCTS

Humans depend on the dietary intake of vitamin B_{12}. Although some plant foods such as certain edible algae and fermented soybeans (tempe) contain some B_{12},[20] only animal-derived foods offer naturally sufficient amounts of cobalamin to meet the body's requirements. The best sources are ruminant meat and milk due to

Table 1 **Recommended dietary intakes for vitamin B_{12}**

Population	Recommended vitamin B_{12} intake (µg/day)	
	Germany, Switzerland, and Austria[a]	United States[b]
Infants		
0–<12 month	0.4–0.8	0.4–0.5
Children		
1–<13 years	1.0–2.0	0.9–1.8
Adolescents and adults		
13 years and older	3.0	2.4
Pregnant women	3.5	2.6
Breastfeeding women	4.0	2.8

[a]Data from the German Society for Nutrition (2013).[5]
[b]Data from the Institute of Medicine (1998).[16]

the natural bacterial populations that synthesize vitamin B_{12} in the rumen of these animals.[3,20] After its bacterial biosynthesis in the animal, vitamin B_{12} is absorbed through the gastrointestinal tract and transported via the blood to body tissues and liquids including the liver, muscles, and milk.[21]

Meat

Livers from ruminant animals contain the largest amounts of vitamin B_{12}, and red meat is another excellent source. The national food composition databases of Denmark, Switzerland, Canada, and the United States present the following vitamin B_{12} concentrations for raw meat: 0.7–5.2 µg/100 g for beef, 1.2–5.0 µg/100 g for lamb/mutton, 1.0–2.9 µg/100 g for veal, 0.4–2.0 µg/100 g for pork, and 0.2–0.6 µg/100 g for chicken. Regarding the vitamin B_{12} content in the livers of different animals, concentrations vary from 59.0 to 110.0 µg/100 g for beef and 60.0 µg/100 g for veal. Values found in kidneys are as follows: 23.0–28.0 µg/100 g for veal and 27.0–31.0 µg/100 g for beef.[22–25] Most food composition databases do not disclose how the values were obtained; therefore, the observable differences within any particular type of meat cannot be explained. However, as discussed below, differences may be due to several factors including the methods of analysis, cooking methods, animal feeding and husbandry practices, and the cut of meat (i.e., type of muscle). Table 2 presents the concentrations of vitamin B_{12} in raw and thermally processed meat, meat products, and organ meats, as documented in the literature.[21,26–40]

Differences according to method of analysis Although the various methods of determining the vitamin B_{12} content in foods correlate well, the results may differ because less selective methods may also detect biologically inactive cobalamins. Typically, the B_{12} concentration is determined by bioassays utilizing microorganisms that require vitamin B_{12}. This is the predominant method in the literature.[26,28,29,32,35,36] Vitamin B_{12} can also be assessed with a radioisotope dilution assay,[21,30,33,38] which yields results comparable to those for the microbiological assay but may, in some cases, give a slightly higher estimate of the B_{12} content.[30,41,42] In two of the investigations reviewed, a chemiluminescence analyzer was used to measure B_{12} concentrations.[31,39] This seems to be both more selective than and well-correlated with the microbiological method used to test most of the foods.[31] Nevertheless, the B_{12} concentration detected in raw pork and chicken muscle (not in beef muscle) was significantly higher with chemiluminescence than with microbiological analysis (pork 3.70 versus 2.42 µg/100 g; chicken 1.73 versus 1.54 µg/100 g).[31] Another method for B_{12} determination in foods that seems to be more sensitive than the microbiological assay is high-performance liquid chromatography.[27,34,40]

Animal differences As mentioned previously, the vitamin B_{12} concentration in ruminant meat such as beef and lamb is usually higher than in the meat of monogastric animals such as pigs and poultry due to the larger bacterial populations that synthesize vitamin B_{12} in the rumen of these animals.[3,20] A comparison of muscle samples from Limousin steers, Charolais heifers, and Charolais and Montbeliard cull cows showed no significant influence of animal breed on the B_{12} concentration of raw meat.[33] However, the older the animal, the higher the vitamin B_{12} concentration tended to be. The levels in beef are, therefore, generally higher than in veal, and mutton usually contains more vitamin B_{12} than lamb.[43]

Differences according to meat cuts The type of muscle has a substantial impact on the vitamin B_{12} concentration, with the orientation of the muscle's energy metabolism being the most probable predictor of cobalamin concentration. Oxidative muscles contain more vitamin B_{12} than glycolytic muscles, supposedly due to the larger number of mitochondria in which adenosylcobalamine is preferentially located.[21,33] In an investigation by Ortigues-Marty et al.,[21] the oxidative-type rectus abdominis muscle (flank) contained 1.08 µg vitamin B_{12} per 100 g compared with only 0.5 µg vitamin B_{12} per 100 g in the glycolytic semi-tendinosus muscle (eye of round). Additionally, vitamin B_{12} is water soluble and associated with proteins. Therefore, cuts of meat with low total lipid content have higher concentrations of B_{12} than cuts with high total lipid content.[33] Different cuts of meat can thus possess substantially different concentrations of cobalamin.

Influence of feeding and animal husbandry Ruminants normally do not have a vitamin B_{12} source in their feed

Table 2 **Vitamin B_{12} concentrations in raw and thermally processed meat**

Type of meat	Vitamin B_{12}(μg/100 g)	Reference
Lamb		
Lean meat, raw	1.12	Heyssel et al. (1966)[26]
Lean meat, raw	3.00–4.02	van Heerden et al. (2007)[27]
Muscle longissimus dorsi, raw	0.55–0.99	Ortigues-Marty et al. (2005)[21]
Muscle semi tendinosus, raw	0.67–1.04	Ortigues-Marty et al. (2005)[21]
Mince, raw	1.7	Williams et al. (2007)[28]
Mince, cooked	2.1	Williams et al. (2007)[28]
Lean meat, cooked	0.2–1.1	van Heerden et al. (2007)[27]
Chop, braised	0.45–2.31	Adams et al. (1973)[29]
Leg, roasted	1.26–2.22	Adams et al. (1973)[29]
Mutton		
Leg roast and casserole, raw	2.8	Williams et al. (2007)[28]
Leg roast and casserole, cooked	1.9	Williams et al. (2007)[28]
Leg, roasted	0.83–2.29	Adams et al. (1973)[29]
Sheep, kidney, braised	52.6–110.4	Adams et al. (1973)[29]
Shoulder, boiled	0.42–1.67	Adams et al. (1973)[29]
Beef		
Primal cuts of separable lean meat, raw	3.50–4.43	Bennink et al. (1982)[30]
Separable lean meat, raw	2.83	Bennink et al. (1982)[30]
Separable lean meat, thermally processed	2.71–2.77	Bennink et al. (1982)[30]
Muscle, raw	1.53	Watanabe et al. (1998)[31]
Liver, raw	62.51	Watanabe et al. (1998)[31]
Strip steak, raw	1.3	Leheska et al. (2008)[32]
Ground beef, raw	2.0	Leheska et al. (2008)[32]
Muscle rectus abdominis, raw	0.91–1.18	Ortigues-Marty et al. (2005)[21]
Muscle semi tendinosus, raw	0.36–0.58	Ortigues-Marty et al. (2005)[21]
Liver, raw	54.1–78.2	Ortigues-Marty et al. (2005)[21]
Muscle triceps brachii, raw	2.09	Ortigues-Marty et al. (2006)[33]
Muscle longissimus lumborum, raw	1.15	Ortigues-Marty et al. (2006)[33]
Muscle longissimus thoracis, raw	0.92	Ortigues-Marty et al. (2006)[33]
Mince-low fat, raw	1.9	Williams et al. (2007)[28]
Mince-low fat, cooked	2.4	Williams et al. (2007)[28]
Various pieces, raw	2.84–3.95	Szterk et al. (2012)[34]
Various pieces, fried	1.48–2.28	Szterk et al. (2012)[34]
Various pieces, grilled	1.03–1.19	Szterk et al. (2012)[34]
Tenderloin, roasted	1.15	Szterk et al. (2012)[34]
Brisket, boiled	1.06–1.36	Adams et al. (1973)[29]
Rump, braised	0.37–1.31	Adams et al. (1973)[29]
Sirloin, roasted	0.67–1.29	Adams et al. (1973)[29]
Shoulder, heated in various ways	0.50–2.22	Adams et al. (1973)[29]
Ox, liver, braised	53.5–111.5	Adams et al. (1973)[29]
Ox, kidney, braised	4.8–7.1	Adams et al. (1973)[29]
Veal		
Lean meat, raw	1.6	Williams et al. (2007)[28]
Lean meat, cooked	3.0	Williams et al. (2007)[28]
Fricassee	0.52–1.58	Adams et al. (1973)[29]
Jellied	0.95–2.17	Adams et al. (1973)[29]
Goat		
Ground meat, grilled	1.09–1.17	Johnson et al. (1995)[35]
Pork		
Chop, braised	0.32–0.47	Adams et al. (1973)[29]
Leg, roasted	0.13–0.82	Adams et al. (1973)[29]
Muscle, raw	3.70	Watanabe et al. (1998)[31]
Lean meat, raw	0.45–0.61	Esteve et al. (2002)[36]
Poultry		
Turkey, breast, roasted	0.41–3.29	Adams et al. (1973)[29]
Turkey, breast, raw	0.47	Molonon et al. (1980)[37]
Turkey, breast, cooked	0.44–0.70	Molonon et al. (1980)[37]
Chicken, red and white meat, cooked	0.19–1.30	Adams et al. (1973)[29]
Chicken, white meat, cooked	0.33–0.43	Doscherholmen et al. (1978)[38]
Chicken, red meat, cooked	0.71–0.83	Doscherholmen et al. (1978)[38]
Chicken, muscle, raw	1.73	Watanabe et al. (1998)[31]

(Continued)

Table 2. **Continued**

Type of meat	Vitamin B_{12} (µg/100 g)	Reference
Meat products		
Sausages, cooked	0.3–1.54	Adams et al. (1973)[29]
Ham, baked	0.34–0.69	Adams et al. (1973)[29]
Ham, dry-cured	0.33–0.67	Lucarini et al. (2013)[39]
Ham, cooked	0.09–0.13	Lucarini et al. (2013)[39]
Ham, smoked	0.33	Lucarini et al. (2013)[39]
Cured meat products	0.41–2.20	Esteve et al. (2002)[36]
Frankfurt sausage	0.60–0.61	Esteve et al. (2002)[36]
Vienna sausage	0.33–0.85	Esteve et al. (2002)[36]
Turkey breast	0.48–3.41	Esteve et al. (2002)[36]
Mortadella	0.56–1.04	Esteve et al. (2002)[36]
Ham, cooked	0.23–0.45	Esteve et al. (2002)[36]
Salami	0.39–0.95	Guggisberg et al. (2012)[40]
Landjäger	0.59–0.81	Guggisberg et al. (2012)[40]
Salsiz	0.96–1.49	Guggisberg et al. (2012)[40]
Saucisson Vaudois	0.44–0.56	Guggisberg et al. (2012)[40]
Coppa	0.23–0.57	Guggisberg et al. (2012)[40]
Bacon, raw	0.36–0.62	Guggisberg et al. (2012)[40]
Ham, raw	0.26–0.68	Guggisberg et al. (2012)[40]
Mostbröckli	1.07–1.63	Guggisberg et al. (2012)[40]
Dried beef	1.12–2.61	Guggisberg et al. (2012)[40]

but they do benefit from the bacteria in their rumen that utilize dietary cobalt to synthesize vitamin B_{12}.[44] Thus, vitamin B_{12} synthesis in ruminants varies depending on the amount of cobalt in the feed. Since a sufficient amount of B_{12} is essential for the animals' health, recommendations exist to ensure an adequate cobalt content of the animal diet.[44,45] With the feed commonly provided, ruminants should be adequately supplied with cobalt and, therefore, with vitamin B_{12}.[46] The results of a study by Ortigues-Marty et al.[21] indicate that diet-induced differences in the B_{12} concentrations of ruminant meat are essentially related to the amount of available cobalt in the animal diet. However, unlike liver concentrations, B_{12} concentrations in muscle were only minimally affected by the feed. The authors presumed that the liver has to be depleted to a certain degree before levels in muscle are reduced.[21]

Influence of thermal processing Vitamin B_{12} is water soluble and sensitive to light as well as to oxidizing and reducing agents such as ascorbic acid, sulfite, and iron salts. Consequently, the thermal processing of fresh meat, such as by cooking, roasting, and braising, influences the available cobalamin content.[42] There are two conflicting effects of thermal processing on vitamin B_{12} concentrations in meat. First, there is a concentrating effect, due to moisture and lipid decreases that occur during cooking. Second, since vitamin B_{12} is water soluble, it can be lost with the water, especially when moist-heat methods are used. In addition, vitamin B_{12} is sensitive to light and oxidation; thus, losses may occur when cooking time is augmented and as a result of certain preparation conditions.[33,37] Several investigations compared the concentrations of vitamin B_{12} in raw meat and in meat that was cooked using dry-heat as well as moist-heat methods.[27,30,33,37] Study results varied, but they predominantly showed an increase in B_{12} content on a fresh-weight basis. Using dry-heat cooking methods, an increase of 15–37% of the initial value was described.[33] However, on a dry matter basis, some significant decreases in vitamin B_{12} concentrations were observed, which could be attributable to the long duration and/or high temperature of cooking. Cobalamin losses of 10–40% caused by cooking are documented in the literature.[30,33] Differences occur based on the cooking method used. However, cooking at a lower temperature results in higher B_{12} concentrations than cooking at higher temperatures.[37] In conclusion, cooked meat seems to offer similar or higher B_{12} concentrations per 100 g edible portion than raw meat due to the moisture and lipid losses that occur during cooking, even though an important part of the vitamin B_{12} content might be lost with the water and destroyed by the cooking method used. This becomes obvious when values are compared on a dry-weight basis.

Influence of meat maturation Between the time of slaughter and consumption, meat is stored; during this period, the meat matures. This period of maturation is widely used to enhance the meat's quality, particularly its tenderness but also its flavor. One study examined the effect of the duration of maturation on vitamin B_{12} content, and no effect was demonstrated.[33]

Milk and dairy products

The national food composition databases of Denmark, Switzerland, and Canada present the following vitamin

B_{12} concentrations: bovine milk, 0.08–0.49 µg/100 g; goat milk, 0.07–0.10 µg/100 g; cheese, 0.34–3.34 µg/100 g; yogurt, 0.12–0.60 µg/100 g; and cream, 0.17–0.50 µg/100 g.[22–24] As mentioned above, concentrations can vary a great deal depending on the method of analysis. Efforts to optimize the analytical methods for B_{12} determination are ongoing. Table 3 summarizes the vitamin B_{12} concentrations in a variety of dairy products.[47–53]

Vitamin B_{12} in milk is mostly bound to proteins.[54] Hydroxycobalamin, adenosylcobalamin, and methylcobalamin represent the major derivatives of B_{12} in bovine milk and hard cheese.[55,56] In bovine milk, B_{12} concentration is stable with regard to breed, feed, season, and stage of lactation (except for colostrum, which contains higher concentrations of B_{12}).[3] However, milk processing results in severe losses of B_{12}. In light of this problem, various experiments have been performed by different working groups and are presented in the sections below.

Thermal processing and storage of milk Arkbage et al.[57] conducted experiments that included the heating and boiling of milk. Temperatures of 76°C for 16 s and 96°C for 5 min did not cause losses of B_{12}. In other studies, however, high losses were observed, e.g., boiling milk for 2–5 min and 30 min resulted in vitamin B_{12} reductions of 30% and 50%, respectively,[58,59] as were minor losses, e.g., <10% loss of vitamin B_{12} after pasteurization and 0–20% loss after ultra-high temperature treatment.[47] Storage of ultra-high temperature-treated milk at 7°C for 18 weeks did not lead to losses of B_{12}, whereas storage at 23°C and 35°C for 18 weeks was accompanied by a significant reduction of up to 33% of vitamin B_{12} concentration. Vitamin retention was strongly dependent on the oxygen concentration in the packaging.[60]

Table 3 **Vitamin B_{12} concentrations in milk and dairy products**

Dairy product	Vitamin B_{12} (µg/100 g)	Reference
Milk		
Cow	0.2–0.7	Renner (1982)[47]
Sheep	0.30	Sieber (2012)[48]
Goat	0.07	Scott and Bishop (1986)[49]
Buffalo	0.3	Souci et al. (2008)[50]
Horse	0.3	Souci et al. (2008)[50]
Human	0.05	Souci et al. (2008)[50]
Skim	0.3	Souci et al. (2008)[50]
Ultra-high temperature	0.38	Souci et al. (2008)[50]
Buttermilk	0.095–0.23	Scott and Bishop (1986)[49]
Cream	0.3	Scott and Bishop (1988)[51]
Fermented milk		
Yogurt	0.17–0.43	Scott and Bishop (1986)[49]
Cheese		
Edam, gouda	1.4–1.9	Scott and Bishop (1988)[51]
Emmentaler	3.1	Sieber et al. (1988)[52]
Blue	1.0–1.2	Scott and Bishop (1988)[51]
Gruyère	2.0	Sieber et al. (1988)[52]
Parmesan	1.5–1.9	Scott and Bishop (1988)[51]
Cottage cheese	2.0	Souci et al. (2008)[50]
Curd	0.38	Sieber et al. (1999)[53]

Milk fermentation and storage of yogurt The addition of starter cultures such as *Lactobacillus bulgaricus* and *Streptococcus thermophilus* for the fermentation of milk to yogurt decreased the original amount of vitamin B_{12} by 25%.[57] Similar results were observed in other studies.[61–63] Storage of yogurt (unopened cup) at 4°C for 14 days caused further losses of 33%. In total, only 40% of the initial amount of B_{12} in milk was present in the prepared and stored yogurt.[57]

Milk fermentation and storage of cheese During the cheese-making process, the whey fraction is removed, leading to a severe loss of vitamin B_{12} due to its water solubility. In one study of six fermented dairy products, cottage cheese contained only 16% of the B_{12} concentration that was initially present in the milk from which it derived, and packaging and storage for 10 days did not alter the vitamin concentration.[57]

During the production of two hard cheeses, 44–52% of the B_{12} originally present in the milk was removed via the whey fraction.[57] A cheese-ripening process of 32 weeks led to further B_{12} losses of 10% for one hard cheese and no further losses for the other. During the production of blue cheese, 38% of the initial B_{12} content was removed with the whey fraction. After 5–6 weeks of ripening and 8 weeks of storage, the vitamin B_{12} content did not decrease further.[57]

Similar results were observed when producing Camembert, blue cheese, Port-Salut, and Gruyère cheeses; in the whey fraction, only 43.0–60.5% of the initial vitamin B_{12} concentrations in the milk were found.[64] Moreover, further losses occurred within the first few days after production and continued during the ripening process in mold cheeses (losses from 38% to 44%). In the cheese rind of Port-Salut, small quantities of B_{12} were formed. Greater B_{12} increases in cheese as well as on the surface were measured in Gruyère due to the application of propionic bacteria. Storage of the cheeses at temperatures between 2°C and −20°C did not change the vitamin B_{12} concentrations.[64]

B_{12}-consuming and B_{12}-producing bacterial strains Lactic acid bacteria require vitamin B_{12} in order to grow. As a result, they contribute strongly to the findings described in this article. In particular, *L. bulgaricus* and *S. thermophilus*, which are commonly used for milk fermentation, were found to be very efficient vitamin

B_{12} consumers.[63] In that experiment, the retention of vitamin B_{12} in yogurt after storage was found to be low; this was most likely due to the storage temperature of 4°C, which is not low enough to inhibit the metabolic activity of lactic acid bacteria. Consequently, the bacteria continue to use B_{12} for growth. Similar results and assumptions were published by Swedish researchers who observed severe losses of B_{12} after milk fermentation, especially in yogurt and kefir.[61]

Bacterial strains that produce vitamin B_{12} have also been identified, including *Propionibacterium* strains, which are regarded as the most efficient vitamin B_{12} producers.[65] In particular, the addition of *Propionibacterium shermanii* to the starter cultures of different milk beverages increased the concentration of vitamin B_{12} in the products.[66] Poonam et al.[67] listed some dairy *Propionibacterium* strains and the concentrations of vitamin B_{12} they produce. However, most *Propionibacterium* strains are not suitable for fermentation of milk; rather, they play an important role in the industrial production of synthetic B_{12}. This area of research has not yet been fully explored, but it is indisputable that these microorganisms have an enormous potential to naturally enrich fermented dairy foods with vitamins or other important micronutrients.

Bioavailability of vitamin B_{12} from food of animal origin

In recent years, scientists have endeavored to evaluate the bioavailability of B_{12} from different food sources. Their aim was, and still is, to optimize the recommended daily allowance of vitamin B_{12}, particularly for children and the elderly who need vitamin B_{12} to develop, maintain, and improve their cognitive performance.[68] Vitamin B_{12} research also focuses on vegans and vegetarians, since their abstinence from foods of animal origin is associated with different states of vitamin B_{12} deficiency.[6] With regard to the bioavailability of vitamin B_{12} from foods, study results vary greatly. The administration of 0.25 µg radioactive-labeled B_{12} via water and milk resulted in absorption rates of 55% (water) and 65% (milk) in elderly people.[69] Similar absorption rates were documented for B_{12} in chicken meat and mutton (Table 4).[26,38,70,71] The B_{12} status in vegetarians was positively correlated with dairy product intake (especially milk) but not with egg or seafood ingestion.[72] Meat, fish, and poultry also showed positive impacts on B_{12} levels in human plasma, albeit less intensively than dairy.[13] A similar observation was reported from a Norwegian study that showed the concentration of B_{12} in human plasma correlates with the ingestion of B_{12} via dairy products and fish but not with intake via eggs or meat.[14] The latter finding is surprising since the bioavailability of B_{12} in meat and liver has been shown to be high.[26,38] The following factors are assumed to play a role in this finding: 1) the B_{12} intake calculated does not conform with actual intake since the cooking of meat influences the available B_{12} concentration[30,58]; 2) the decreasing rates of absorption with increasing B_{12} concentrations (see description below) favors the repeated consumption of low doses of B_{12} (as in regular consumption of milk products) instead of one large dose (as in one large portion of meat)[73]; and 3) people with reduced gastric secretion possibly have problems digesting collagen-rich foods such as meat, which leads to a reduced release of B_{12}.[14] Contrary to this last observation, a study of Kenyan schoolchildren demonstrated that consumption of a meal including either meat or milk 5 days per week for 9 months significantly improved plasma B_{12} concentrations.[74] After 2 years of intervention, the prevalence of children with low plasma vitamin B_{12} levels (<148 pmol/L) was reduced in both groups, changing from 55.6% to 4.5% in the meat group and from 41.0% to 8.9% in the milk group.

For synthetic vitamin B_{12}, the scientific literature presently reports a bioavailability of <4% in humans and animals, which is quite low.[75] The bioavailability of natural B_{12} isomers from raw and processed cows' milk (pasteurized or microfiltered) compared with synthetic cyanocobalamin and with a B_{12}-free control diet was investigated in a Canadian crossover study with pigs. It was found that dietary concentrations of cobalamin correlated inversely with bioavailability.[76] This effect was previously described for humans as well.[7] The more B_{12} that is consumed, the less will be absorbed. This phenomenon is due to saturation of the vitamin B_{12}–IF receptors in the small intestine, which is estimated to be reached at concentrations of 1.5–2.0 µg per single meal under physiological conditions.[73,77] It is suggested that 50% of 1 µg of ingested vitamin B_{12} is absorbed, dropping to 10% when 10 µg is ingested and to only 5% when the intake is 20 µg. However, very high doses of cobalamin enable 1% absorption of B_{12} by passive diffusion (e.g., 5 µg of a 500-µg supplement[65]). Doets et al.[17] recently reviewed daily vitamin B_{12} losses and bioavailability using a factorial approach. Data from eight studies that included 83 participants showed an increase in vitamin B_{12} absorption with increasing doses of vitamin B_{12} intake (food of animal origin). A meta-analysis published by the same group found an 11% increase of plasma vitamin B_{12} concentration in humans after intake of the vitamin was doubled (mainly through B_{12}-enriched foods). This effect was stronger in elderly participants (13%) than in adults (8%).[78] In general, the Institute of Medicine takes into account an average dietary B_{12} absorption rate of 50% by healthy individuals with

Table 4 **Bioavailability of different amounts of B_{12} from food sources**

Food source	Amount of B_{12} (μg)	Bioavailability (%)	Reference
Cooked mutton	0.9[a]	56–77	Heyssel et al. (1966)[26]
	3.0[a]	76–89	
	5.1[a]	40–63	
Chicken meat	0.4–0.6[a]	65	Doscherholmen et al. (1978)[38]
	0.8–1.3[a]	63	
	1.3–1.9[a]	61	
Liver	38.0	4.5/9	Heyssel et al. (1966)[26]
Milk	0.25[a]	65	Russell et al. (2001)[69]
Egg	1.1–1.4/100g		Squires and Naber (1992)[70]
Scrambled egg yolks		8.2	
Scrambled whole eggs		3.7	
Boiled eggs		8.9	
Fried eggs		9.2	
Fish	2.1[a]	42	Doscherholmen et al. (1981)[71]
	4.1[a]	38	
	9.2[a]	42	
	13.3[a]	30	

[a]Total amount of vitamin B_{12} for intake.

Table 5 **Contribution of meat and meat products and of milk and dairy products to total vitamin B_{12} intake according to country**

Country	Contribution of meat and meat products to total B_{12} intake (%)	Contribution of milk and dairy products to total B_{12} intake (%)	Reference
Switzerland	58	27	Schmid et al. (2012)[81]
France	42	9	Volatier and Dufour (2007)[82]
The Netherlands (young children)	NA	58	Vissers et al. (2011)[83]
The Netherlands (adults and elderly)	NA	44–46	Vissers et al. (2011)[83]
United States	20–40 (beef and lamb meat, liver, burgers)	NA	Sharma et al. (2013)[84]
United States (19–50 years)	25 (lean beef)	NA	Zanovec et al. (2010)[85]
United States (>50 years)	20 (lean beef)	NA	Zanovec et al. (2010)[85]

Abbreviations: NA, not available.

normal intestinal functions.[16] Further clarification of these data is needed.

Contributions of meat and milk to total vitamin B_{12} intake

One portion (120 g) of cooked meat may meet 5–132% of recommended daily B_{12} intake (3.0 μg) when calculations are based on the values given in Table 2. Dietary guidelines recommend daily consumption of three servings of dairy products.[79,80] Based on Table 3, three glasses of milk (250 mL/glass) would supply 1.5–5.25 μg vitamin B_{12}. One portion of milk, one of cheese (hard variety, 60 g), and one of yogurt (150 g) would provide 1.6–4.3 μg/d vitamin B_{12}.

Table 5 summarizes the extent of the contributions made by meat and meat products as well as milk and dairy products to vitamin B_{12} intake in different countries.[81–85] The contributions vary according to national consumption habits and fortification practices. For example, in the United States, beef and lamb meat as well as liver and burgers/patties are among the top 10 food sources of vitamin B_{12}. However, cereals are the single top contributor to vitamin B_{12} intake because they are fortified with the vitamin.[84] In countries such as Switzerland, in which fortification of cereals is not as extensive as in the United States, the portion of vitamin B_{12} obtained from meat and dairy products is naturally greater.[81] Available data suggest that meat and dairy products are important contributors to vitamin B_{12} intake in many Western countries. Thus, it is not surprising that a study of female university students found a decrease in the average B_{12} intake that was below recommendations (from 3.9 to 1.2 μg) when more than one foodstuff from the meat and poultry group was eliminated.[86]

CONCLUSION

Through consumption of meat, milk, and dairy products, it is possible to meet a substantial portion of human requirements for vitamin B_{12}. In particular, meat from ruminants (containing between 0.36 and 4.43 μg of B_{12}) and liver are valuable sources of the vitamin.

The vitamin B_{12} concentrations in milk and dairy products are lower than in meat; nevertheless, they contribute substantially to meeting the recommended intake of cobalamin in many Western countries. The processing of both meat and milk, especially thermal treatment of these foods, leads to severe losses of vitamin B_{12}. However, compared with raw meat, cooked meat offers similar or even higher B_{12} concentrations per 100 g edible portion due to moisture and lipid losses that occur during cooking. In terms of ruminant food processing, dairy fermentation plays a unique role since the fermenting bacteria are not only B_{12} consumers but, in some cases, B_{12} producers. This finding offers a broad field of new possibilities for naturally enriching ruminant foods with cobalamin, thereby ensuring an appropriate B_{12} supply among the world's population.

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