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Water Soluble Vitamins

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Abstract

Vitamins support human brain, metabolism, skin, pregnancy, energy and act as antioxidants. Most of them are soluble in water: vitamins B1, B2, B3, B5, B6, B7, B9 (folate), B12 and C. While B1–B7 can be found in a variety of sources with moderate environmental impact, and vitamin C in unprocessed fruits and vegetables, others are more challenging. Deficiencies in B9 and B12 are quite common due to low consumption of wholegrains, vegetables and organ meats. Considering water and carbon footprint, new food products shifted toward plant based solutions. Since palatability is a challenge, innovative technologies produced tasty alternatives by embracing the potential of legumes and upcycled ingredients, such as pasta made with pulse flour or defatted flour (B1–B9). A curios eye has been opened on overlooked treasures such as microalgae (vitamin B12). Finally, minimally processed fruits and vegetables can be a solution to supply vitamin C and shelf-life (challenging for produce).

Keywords

B vitamins · B12 · Folate · Fruits · Meat · Vitamin C · Wholegrains

7.1 Water Soluble Vitamins for Human Nutrition

Vitamins are essential micronutrients for human health. Micronutrients means that we only need small amounts, in the order of mg or µg, to support our daily needs. Nonetheless, they are just as important as micronutrients. Vitamins is a very broad term. Typically, we classify them in two types, based on their chemical affinity to solvents: water soluble and fat soluble (Tyśkiewicz et al., 2018). This chapter focusses on water sol-

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uble vitamins, which include vitamins B1, B2, B3, B5, B6, B7, B9, B 12 and C.

Vitamin B1 is chemically known as thiamine. Chemically, it is a sulphur-containing compound. It is mostly found in the husk and germ of wholegrains, followed by lower concentrations in foods such as meat, seafood, produce, dairy, nuts and seeds. Its deficiency leads to a disease known as beriberi, resulting in cardiovascular diseases (wet beriberi) and damage to the nervous systems (dry beriberi) (DiNicolantonio et al., 2018; NIH, 2021a). Vitamin B2 is also known as riboflavin. It is found primarily in beef liver, wholegrains and dairy. It is essential for the production of energy and the metabolism of fat soluble nutrients and iron. Its deficiency causes dysfunctions in the absorption of fats, iron and vitamins and, possibly, cancer (NIH, 2021b; Saedisomeolia & Ashoori, 2018; Thakur et al., 2017). Vitamin B3 is niacin, and it can be found in animal liver. Meat, salmon and, to lower extents, in grains. Niacin is essential for energy metabolism. When deficient in B3, humans may exhibit a skin disease known as pellagra (NIH, 2021c; Prabhu et al., 2021). Vitamin B5 is pantothenic acid; it is found abundantly in a vast variety of foods: beef liver, mushrooms, sunflower seeds, chicken, tuna, produce and many more (NIH, 2021d). Biologically, it supports the metabolism of numerous nutrients, preventing fatigue and digestive disorders (Maqbool et al., 2018). Vitamin B6 is actually a group of compounds, which are particularly important for cognitive development and brain functions. These compounds abound in chickpeas, beef liver and seafood. Deficiency in vitamin B6 can result in cardiovascular disease and even cancer (Kumrungsee et al., 2021; NIH, 2021e). Vitamin B7, biotin, is needed to metabolize glucose, amino acids and fatty acids. Its deficiency It is typically bound to protein in beef liver, eggs, seafood, pork, seeds, nuts and vegetables such as sweet potatoes, broccoli and spinach (NIH, 2021f; Scott, 2020).

Vitamin B9 is known as folic acid or folate. It is very well known for its role in pregnancy (Argyridis, 2019). It is essential for healthy development of the neural tube as well as red blood cells. Folic acid is found in beef liver, spinach, wholegrains and green leafy vegetables. Its deficiency can cause serious birth defects and megaloblastic anemia (Argyridis, 2019; NIH, 2021g).

Vitamin B12 is chemically cobalamin. It has the unique feature of a cobalt ion at the core of its structure. It is often discussed along with B9, due to their role in red blood cells development. Furthermore, it is essential for healthy brain and nervous system. Its reliable food sources are animal based: liver, meat, fish, dairy and eggs. Plant sources such as microalgae, seaweeds and fermented foods are, as of today, not consistent. Its deficiency causes serious megaloblastic anemia and brain disorders (NIH, 2021h; Rizzo & Laganà, 2020).

Vitamin C is technically an acid: ascorbic acid. It is needed as antioxidant, for healthy skin, nutrient absorption and collagen production, Deficiencies in ascorbic acid result in numerous diseases, including scurvy. Vitamin C is found only in fruits and vegetables (NIH, 2021i; Wong et al., 2020).

This chapter will present challenges and opportunities for water soluble vitamins, in terms of nutrition, sustainability and food quality. Vitamins B1, B2, B3, B5, B6 and B7 will be grouped together. Vitamins B9, B12 and C will be discussed separately due to their unique bioactivities. An example of the modern trajectory of food products rich in water soluble vitamins is depicted in Figs. 7.1–7.4.

7.2 Traditional Food Sources of Water Soluble Vitamins

7.2.1 Vitamins B1, B2, B3, B5, B6, B7

B1 (Thiamine) Brown rice is a typical example of food rich in vitamin B1. A 100 g serving if brown rice delivers half of the recommended daily intake (RDI) (NIH, 2021a) (Table 7.1). This type of rice is less refined than its white counterpart, with the outer husk removed while bran and germ are maintained (Aung, 2017). That is where vitamin B1 is found: husk, bran and germ (Balakrishna & Farid, 2020). The environmental

Fig. 7.1 Representative sources of vitamin B1: traditional (brown rice) and innovative (oat milk)

Fig. 7.2 Representative sources of vitamin B9: traditional (spinach) and innovative (lentil pasta)

footprint of brown rice is moderate, with 2,172L water required and 1.2 kg CO_2 emitted per kg of product (Kashyap & Agarwal, 2021; Mekonnen & Hoekstra, 2011). From a consumer standpoint, price is affordable at 0.35 NZD/100 g (Countdown, 2021) while sensory can be polarizing: brown colour and chewy texture may not appeal everyone (Gondal et al., 2021) along with longer cooking time than white rice, but the nutty flavour adds positively to the eating experience.

Fig. 7.3 Representative sources of vitamin B12: traditional (tuna) and innovative (microalgae such as spirulina)

Fig. 7.4 Representative sources of vitamin C: traditional (strawberries) and innovative (blackcurrant powder)

B2 (Riboflavin) Dairy products can deliver high amounts of vitamin B2, equal to 21% of the RDI (NIH, 2021b) (Table 7.1). Vitamin B2 in Greek yoghurt is highly bioavailable because calcium acts as a pathway to transport the riboflavin to the small intestine. Furthermore, milk products e.g. yoghurt contain significant concentrations of free riboflavin bound to proteins which makes it easy to absorb through the FAD and FMN cofactors of proteins (Powers, 2003). The environmental footprint is quite high, particularly in regards to carbon emissions: 4.5–6.8 kg CO_2/kg Greek yoghurt

Table 7.1 Representative food sources of water soluble vitamins: products, nutritional value (quantity, quality as % of the recommended daily intake RDI), sustainability (water and carbon footprint) and consumer acceptability (price, sensory)

	Nutrition		Sustainability		Acceptability	
Food products	quantity (per 100 g)	Quality (%RDI)	Water footprint (L water/kg product)	Carbon footprint (kg CO_2/kg product)	price (NZD/100 g)	Sensory profile
Vitamin B1 (thiamin)						
Brown rice	0.67 mg NIH (2021a)	56% NIH (2021a)	2,172 Mekonnen and Hoekstra (2011)	1.2 Kashyap and Agarwal (2021)	0.35 Countdown (2021)	Brown, chewy Gondal et al. (2021)
Vitamin B2 (riboflavin)						
Greek yoghurt	0.27 mg NIH (2021b)	21% NIH (2021b)	647 (whey) Owusu-Sekyere et al. (2017)	4.5–6.8 Houssard et al. (2020)	0.60 Countdown (2021)	Thick, creamy, slimy, smooth, sour Karagul-Yuceer and Drake (2006)
Vitamin B3 (niacin)						
Peanut butter	13 mg USDA (2019)	81% NIH (2021c)	3,740 Vanham et al. (2020)	2.5 Rahmadi et al. (2021)	1.6 Countdown (2021)	Brown, oily, nutty, spreadable Shibli et al. (2019)
Vitamin B5 (pantothenic acid)						
Beef liver	10 mg NIH (2021d)	198% NIH (2021d)	15,712 Gerbens-Leenes et al. (2013)	18–25 Buratti et al. (2017)	1.7 New Zealand Fresh (2021)	Dark red, friable, off-flavour Kolbábek et al. (2019)
Vitamin B6						
Chickpeas, canned	0.67 mg NIH (2021e)	39% NIH (2021e)	2,071 Kampman et al. (2008)	0.18 Yaghubi et al. (2021)	0.50 Countdown (2021)	Acceptable Kinfe et al. (2015)
Vitamin B7 (biotin)						
Beef liver	37µg NIH (2021f)	123% NIH (2021f)	15,712 Gerbens-Leenes et al. (2013)	18–25 Buratti et al. (2017)	1.7 New Zealand Fresh (2021)	Dark red, friable, off-flavour Kolbábek et al. (2019)
Vitamin B9 (folate)						
Spinach	437µg NIH (2021f)	109% NIH (2021f)	292 Mekonnen and Hoekstra (2011)	0.4 Wang et al. (2019)	0.6 Countdown (2021)	Green, glossy Koyama et al. (2021)
Beef liver	256µg NIH (2021f)	64% NIH (2021f)	15,712 Gerbens-Leenes et al. (2013)	18–25 Buratti et al. (2017)	1.7 New Zealand Fresh (2021)	Dark red, friable, off-flavour Kolbábek et al. (2019)
Vitamin B12 (cobalamin)						
Beef liver	84µg NIH (2021g)	3500% NIH (2021g)	15,712 Gerbens-Leenes et al. (2013)	18–25 Buratti et al. (2017)	1.7 New Zealand Fresh (2021)	Dark red, friable, off-flavour Kolbábek et al. (2019)
Tuna	11µg NIH (2021g)	458% NIH (2021g)	Not available	6.1 Rahmadi et al. (2021)	2.3 Countdown (2021)	Fishy, oily, hard, salty Caponio et al. (2010)

(continued)

Table 7.1 (continued)

	Nutrition		Sustainability		Acceptability	
Food products	quantity (per 100 g)	Quality (%RDI)	Water footprint (L water/kg product)	Carbon footprint (kg CO_2/kg product)	price (NZD/100 g)	Sensory profile
Vitamin C						
Strawberries	68 mg NIH (2021h)	76% NIH (2021h)	347 Mekonnen and Hoekstra (2011)	0.9–1.0 Mordini et al. (2009)	1.4 Countdown (2021)	Red, sweet, floral taste Jouquand et al. (2008)
Orange juice	50 mg NIH (2021h)	56% NIH (2021h)	1,018 Mekonnen and Hoekstra (2011)	0.5–0.8 Roibás et al. (2018)	0.25 Countdown (2021)	Orange, sweet, sour Kim et al. (2013)

(Houssard et al., 2020). This is due to cows farming, milk processing and whey purge: Greek yoghurt is more concentrated than other yoghurt types, thus increasing its nutritional density as well as its waste production (whey). Price is moderate (0.60 NZD/100 g) (Countdown, 2021) while the sensory experience is pleasant: creamy, smooth, thick, with sur notes (Karagul-Yuceer & Drake, 2006).

B3 (Niacin) Peanut butter can be your vitamin B3 fix. 100 g of this spread can deliver 13 mg of vitamin B3 (USDA, 2019), this means 81% of the RDI (NIH, 2021c) (Table 7.1). Obviously, nobody eats that much peanut butter, but even a regular serving size of about 40 g will cover roughly 30% of your needs. Vitamin B3 is easily absorbed into the body from the foods peanut butter. The process begins by the tissues in our body converting the absorbed B3 into the co enzyme nicotinamide adenine dinucleotide (NAD). Following this process NAD is converted to NAPD. These two coenzymes are essential within the body for oxidising the reduction of substrates in the cells. The plant based food of peanut butter provides nicotinic acid mainly and on average 2–5 mg of niacin per serving, which is highly bioavailable in the body (NIH, 2021c). Peanuts are very resourceful in terms of their water consumption due to the physical feature of them being a deep rooting crop which in turn gives them a large amount of water to draw from. In addition, they are a legume and fixate their own nitrogen, hence saving on water usage. Secondly, peanuts are a biomass crop which means they need very little foliage compared to that of other crops (seed varieties). Peanut butter therefore has a lower water footprint compared to that of other nuts. Thus means that other nut butters like almond, cashew, and hazelnut all have a higher water consumption at this stage of the supply chain whilst the primary product of the nut is being grown on farm. The water value is still high as compared to other foods (3,740 L/kg) (Vanham et al., 2020) and 2.5 kg CO_2/kg (Rahmadi et al., 2021). One of its strengths is the low price (1.65 NZD/100 g) (Countdown, 2021) and the nutty, spreadable features (Shibli et al., 2019). Peanut Butter is an acquired taste and many people either love it or dislike it. The two different categories of peanut butter include crunchy and smooth. Smooth peanut butter is very creamy and has been made into a thick fine paste whereas this is compared to crunchy peanut butter which has small segments of whole peanuts. The overall sensory profile of peanut butter is salty, sweet and with earthy undertones making you crave something to drink like a glass of water straight after due to it sticking to the roof of your mouth. Peanut butter also has a slightly savoury taste hence why it can be added to savoury meals.

B5 (Pantothenic Acid) Beef liver can provide plenty of vitamin B5. In fact, 100 g of beef liver offer double the RDI of vitamin 5 (NIH, 2021d) (Table 7.1). That is due to the ability of liver to store multiple micronutrients. This nutritional potential comes at a cost: over 15,000 L of water are needed to produce 1 kg of beef liver (Gerbens-Leenes et al., 2013), with an astounding 18–25 kg CO_2 emitted in the atmosphere (Buratti et al., 2017). Cows farming requires plenty of resources for feed, fertilizer and care of the animals. Carbon emissions result from agriculture to produce of cows' feed (crops), animals themselves (production of methane by cows digestive system) and food processing. Price is quite high (1.7 NZD/100 g) (New Zealand Fresh, 2021) while its taste is polarizing: intense, friable, with some of-flavour and bitter notes (Kolbábek et al., 2019).

B6 Chickpeas, the humble legume, are one of the grains that contain the complex of vitamin B6. As little as 100 g of cooked chickpeas provide 39% of the RDI (NIH, 2021e) (Table 7.1). Nutritionally and environmentally friendly, chickpeas production and processing require moderate amounts of water (2071 L/kg) (Kampman et al., 2008) and produce very little emissions (0.18 kg CO_2/kg) (Yaghubi et al., 2021). Furthermore, chickpeas are cheap (0.50 NZD/100 g canned chickpeas) (Countdown, 2021) and quite neutral in taste, satisfying numerus consumers.

B7 (Biotin) Beef liver once again rises to the top of micronutrient sources. A 100 g serve of beef liver cover more than the full daily need of vitamin B7 (NIH, 2021f) (Table 7.1). As stated for vitamin B5, environmental and price challenges occur, raising the need for innovative solutions to this challenge.

7.2.2 Vitamin B9 (Folate)

Spinach and beef liver are excellent sources of vitamin B9, delivering 109% and 64% of the RDI, respectively (Table 7.1). What elevates spinach to a higher rank is their extremely low footprint, both for water use (292 L/kg) (Mekonnen & Hoekstra, 2011) and carbon emission (0.4 kg CO_2/kg) (Wang et al., 2019). On top of that, spinach are affordable (0.6 NZD/100 g), with only sensory representing a challenge, due to their dark green colour and bitterness (Koyama et al., 2021).

7.2.3 Vitamin B12 (Cobalamin)

Animal food contains vitamin B12. Of course beef liver made it to the list, but also tuna is high in the ranks. The values are astonishing: 3,500% and 458% of the RDI in 100 g of food, respectively (NIH, 2021g) (Table 7.1). Luckily, there are not known cases of diseases caused by high intake of vitamin B12. The high concentration can partially solve the environmental issue, but it is not enough. Generally speaking, seafood has a lower footprint than red meat: for example, carbon emissions are three to four times lower for tuna than beef liver (Table 7.1). What these statistics don't say, is the effect of fishing and aquaculture on marine biodiversity. The growing human population is increasing the demand for fish and seafood. Consequently, more animal species are now classified as threatened to extinction, particularly in the Americas, South East Asia and Oceania. Therefore, intensive fishing and aquaculture will likely contribute to global warming (Blanchard et al., 2017).

7.2.4 Vitamin C

Fresh fruits are the most traditional way to guarantee access to vitamin C. Honourable mentions are certain vegetables such as bell peppers and broccoli, to mention a few. A 100 g serving of strawberries can guarantee 76% of the RDI, while 100 ml of orange juice provide 56% (NIH, 2021h). Most of us grew up with the knowledge that orange juice is the best source of vitamin C but, as you can see, there are even better sources, including other fruits (e.g. kiwifruit and vegetables). Keri Juicing exposes oranges to oxygen, heat and light, accelerating oxidation and degradation of vitamin C and loss of flavours. The taste retains the sweet and sour taste of oranges, but lacks the chewiness of the pulp. (Ivanova et al., 2017). Environmentally, most produce has limited impact. The only negative note is for processed fruits such as the case of orange juice, having triple water footprint than strawberries. This is due to the amount of added resources needed for processing, storage and packaging (Mekonnen & Hoekstra, 2011). In addition, juicing causes loss in insoluble nutrients such as fibre and certain phytochemicals, minerals and vitamins (Bai et al., 2013). Both fruit products are sweet and highly acceptable. Prices vary highly based on seasonality and geographical location. Local and season produce should be preferred for environmental reasons (lower footprint), enhanced sensory and nutritional properties with lower cost (less transport).

7.3 Innovative Food Sources of Water Soluble Vitamins

7.3.1 Vitamins B1, B2, B3, B5, B6, B7

B1 (Thiamine) Vitamin B1 is found in wholegrains, but their high-fibre taste might limit its consumer appeal. A pleasant exception to that is oat products. Oat milk is a growingly popular beverage, it is a good source of B1 since it is a drink made out of oats, upon blending and filtering. Therefore oat milk contains high levels of this water soluble vitamins, without the hard husk of oats. It is as high as 37% of the RDI in 100 ml (NIH, 2021a; Otis, 2021; Robinson, 1949) (Table 7.2). That means that a 250 ml serve of oat milk can fully cover our B1 daily need. Environmentally, oat harvesting only requires moderate levels of water (1,778 L) (Mekonnen & Hoekstra, 2011) while releasing very little carbon: 0.55 kg CO_2/kg (Rajaniemi et al., 2011). On top of that, oat milk is quite nice in taste. The only challenge resides in the creaminess: higher than that of other plant beverages, but still lower than that of dairy milk. Novel technologies, sometimes coupled with the use of syrups, seem to be solving this challenge, resulting in a line of so called "Barista" style oat milk.

B2 (Riboflavin) Almond Mylk is a concentrate made of almonds. Almonds contain 85% of the RDI for B2 (Karimi et al., 2021; NIH, 2021b; vvmylk, 2021) (Table 7.2). This product is meant to be used as an additive to various foods and beverages such as smoothies, coffee, pasta, ice cream etc. for its nutrition and flavour. A 250 ml serve of this concentrate will make up to 4 L of almond milk (vymylk, 2021). The benefits this product offers are an additive free almond product with a long shelf life of 1 year. Though processed into a paste/liquid form, the almond product retains a large amount of its original nutritional value. Almond Mylk is promoted as a sustainable and clean label product. The label of the product claims both 'zero waste' and 'zero added'. The 'zero waste' refers to the use of the whole almond in the product and the 'zero added' refers to no other ingredients, including preservatives, additives or artificial colours, being added to the product. This, at least, is what the company claims. In fairness, almonds do present a big challenge in terms of sustainability. Producing 1 kg of almonds involves huge loads of water (16,095 L) (Mekonnen & Hoekstra, 2011), while processing into almond milk causes large CO_2 emissions (7.1–7.2 kg/kg) (Winans et al., 2020). Therefore, almond milk concentrate can be seen as a treat, but perhaps not a staple food.

B3 (Niacin) Powdered peanut butter is just as good as peanut butter at delivering vitamin B3. The vitamin content is similar, at around 75% RDI (Bonku et al., 2020; NIH, 2021c; Nothing Naughty, 2021) and so is the environmental impact (Table 7.2). What differs is that this ingredient is upcycled, being a by-product of the peanut oil industry. Consequently, it takes pressure off the environment by transforming waste material into a new functional ingredient for human consumption. It is also high in protein and potentially open to numerous applications: bakery, confectionary, and so on.

Table 7.2 Innovative food sources of water soluble vitamins: raw materials, bioavailability (quantity, quality as % of the recommended daily intake RDI) and sustainability (water and carbon footprint)

Products	Raw materials	Bioavailability	Sustainability	
		Vitamin quantity (per 100 g) and %RDI	Water footprint (L water/kg product)	Carbon footprint (kg CO_2/kg product)
Vitamin B1 (thiamine)				
Oat Milk	Oats	0.6 mg (37%) NIH (2021a), Otis (2021) and Robinson (1949) 10% oats	1,778 Mekonnen and Hoekstra (2011)	0.55 Rajaniemi et al. (2011)
Vitamin B2 (riboflavin)				
Almond milk concentrate	Almonds	1.1 mg (almonds) (85%) Karimi et al. (2021), NIH (2021b) and vvmylk (2021)	16,095 (almonds) Mekonnen and Hoekstra (2011)	7.1–7.2 (almond milk) Winans et al. (2020)
Vitamin B3 (niacin)				
Powdered defatted peanut butter	Peanuts	27 mg (169%) Bonku et al. (2020), NIH (2021c) and Nothing Naughty (2021)	3,740 Vanham et al. (2020)	2.5 Rahmadi et al. (2021)
Vitamin B5 (pantothenic acid)				
Lentil chips	Lentils	0.6 mg (12%) Enjoy Life Foods (2021), NIH (2021d) and USDA (2019)	5,874 Mekonnen and Hoekstra (2011)	0.29–0.60 MacWilliam et al. (2018) and Nategh et al. (2021)
Vitamin B6				
Tofu sausages	Soybeans	1.3 mg (75%) Roth-Maier et al. (2002) and Tonzu (2021)	2,145 Mekonnen and Hoekstra (2011)	0.27 Agri footprint (2021)
Vitamin B7 (biotin)				
Defatted sunflower flour	Sunflower seeds	7.5µg (25%) NIH (2021f) and Pal (2011)	3,366 Mekonnen and Hoekstra (2011)	0.88 Yousefi et al. (2017)
Vitamin B9 (folate)				
Lentil pasta	Lentils	479µg (120%) NIH (2021g) and San Remo (2021)	5,874 Mekonnen and Hoekstra (2011)	0.29–0.60 MacWilliam et al. (2018) and Nategh et al. (2021)
Roasted chickpea snacks	Chickpeas	308µg (77%) Happy Snack Company (2021) and NIH (2021g)	4,177 Mekonnen and Hoekstra (2011)	0.18 Yaghubi et al. (2021)
Vitamin B12 (cobalamin)				
Lentein powder	Duckweed (water lentils)	2.2µg (92%) Lentein (2021) and NIH (2021h)	Not available	0.40 De Beukelaar et al. (2019)
Greek yogurt	Milk	1.2µg (50%) (milk) Matte et al. (2012) and NIH (2021h)	1,020 Hayek et al. (2021)	3.0 Hayek et al. (2021)
Vitamin C				
Kiwifruit juice	Kiwifruit	62 mg (69%) Dumbravă et al. (2016) and NIH (2021i)	80–100 Soyergin (2016)	0.15–0.20 (integrated, organic) Müller et al. (2015)
Blackcurrant powder, nootropic beverage	Blackcurrants	940 mg (235%), 5 mg (6%) Ārepa (2021), NIH (2021i) and ViBeri (2021)	499 (fruit) Mekonnen and Hoekstra (2010)	Unknown

B5 (Pantothenic Acid) Lentil chips have been introduced to the crisps market in recent years along with kumara, beetroot and many more types of plant based crisps. The global vegetable crisps market is increasingly growing at a stable rate shown by the CAGR rate increasing by 9.81% between 2017 and 2021. Lentil crisps composition consists of 50% lentil flour, potato starch, sunflower oil, safflower oil, and sea salt (Countdown, 2021). They are nutritionally dense in protein, fibre, vitamins and minerals, however are fairly expensive. Lentil crisps are made by a significant amount of pressure and light to turn the lentil flour into a puffy crisp. The crisps are then baked in the oven and seasoning is added, as opposed to fried (Simply7, 2017). Lentils have become popular as people are beginning to change to plant-based diets due to the increased health benefits which this diet has to offer. There are a number of health benefits associated with the consumption of lentils. Lentils are good sources of fibre, vitamins, minerals, and contain antioxidants which reduce inflammation (Thavarajah et al., 2015). Specifically, 100 g of lentils contains 0.6 mg of B5 (12% RDI) (Enjoy Life Foods, 2021; NIH, 2021d; USDA, 2019) (Table 7.2). Lentils contain specific carbohydrates and fibre which human bodies don't have the ability to digest. They also contain antinutrients which decrease the amount of nutrients and vitamins extracted from the food meaning B5 and other nutrients is difficult to absorb form the food. The antinutrient levels can be reduced however, by dehulling, soaking, cooking, roasting, germination and/or fermentation (Patterson et al., 2017). In addition, consuming this food in combination with a source of vitamin C, such as fresh fruit or vegetables, will accelerate the degradation of the antinutrients, thus releasing micronutrients for human to absorb. The water footprint of lentils is significantly high: almost 6000 L/kg (Mekonnen & Hoekstra, 2011). Nonetheless, pulse crops are nitrate-fixing crops which enhance soil fertility and decrease the need for chemical fertilisers. Pulse crops can also reduce nitrate leaching within the soil profiles and increases the protein within the wheat which in turn increases revenue generated from the crop (Ding et al., 2018). This results in a negligible carbon emission ranging from 0.29 to 0.60 kg CO_2/kg (MacWilliam et al., 2018;融 Nategh et al., 2021).

Vitamin B7 (Biotin) While beef liver is an excellent source of vitamin B7, plants do contribute to its intake as well. In this regard, lower amounts of micronutrients and lower footprint are the result. A good example? Defatted sunflower flour. This is a great case of upcycling. The oil industry leaves behind plenty of nutrients in a fibrous, hard to cook with meal. Appropriate processing, such as extrusion and high pressure, can micronize (reduce in size) the insoluble fibre, making it more soluble. The result is a highly versatile flour, which also delivers vitamin B7: sunflower seeds contain 25% of the RDI (NIH, 2021f; Pal, 2011). Once the oil is removed, it is possible that this number will increase, possibly double (half of these seeds is oil), nut it hasn't been verified yet. This comes with potential applications such as high protein pasta, featuring a characteristic dark grey colour. To testify this, a USA company (Planetarians) provided the ingredient to two Italian pasta companies (Amadori and Barilla) (Food Navigator, 2019). Sunflower seeds have moderate impact on the environment: about 3000 L water and less than 1 kg CO_2 produced per kg (Mekonnen & Hoekstra, 2011; Yousefi et al., 2017). Therefore, the use of their upcycled flour could result in low impact source of vitamin B7.

7.3.2 Vitamin B9 (Folate)

As states above, pulses like lentils are a powerhouse for B vitamins. This include B9, with as much as 120% of the RDI in 100 g of lentils (NIH, 2021g) (Table 7.2). It is not just chips, but also pasta (San Remo, 2021). Lentil pasta is part of a recent trend toward alternative protein, high fibre and gluten-free. The nutritional benefits are many, while the taste is not the same as traditional pasta, being chewy and earthy. Therefore, this product should be consumed as something new rather than a new pasta type. There is a catch though! Pasta is cooked by boiling. Since B9 is water soluble chances are that it might leach into the cooking water, thus never being consumed. There are currently no studies on this, but it is a legitimate concern. While lentil pasta might be a great source of protein and fibre, it may not be the best way to cook your lentils when looking at water soluble vitamins.

Therefore, a better approach could be roasting your pulses. This is the case of roasted chickpea snacks (Happy Snack Company, 2021). Chickpeas contain 77% of the B9 RDI (NIH, 2021g) (Table 7.2). The roasting process is not known to decrease B9 content, thus making roasted chickpeas a good choice in this sense. Environmentally, chickpeas require less water than other pulses and are also responsible for lower carbon emissions (0.18 vs. 0.29–0.60 kg CO_2/kg) (MacWilliam et al., 2018; Nategh et al., 2021; Yaghubi et al., 2021), although this parameter should factor in industrial process. Chickpeas perform well in locations with dry conditions, and prefer a well-draining soil type, therefore demanding less water. This is due to the plants having a deep root system (Ahmad et al., 2005).

7.3.3 Vitamin B12 (Cobalamin)

It is well-established that only animal foods are reliable sources of vitamin B12. Microbes produce it, animals store it in their flesh, eggs and milk. Interestingly though, there have been cases where plant contained this nutrient, such as for duckweed. Duckweed/water lentils have been dried and turned into powder form to incorporate into smoothies as a form of a vegan B12 but also in multiple other vitamins and minerals, estimating a B12 content equal to 92% RDI (Lentein, 2021; NIH, 2021g) (Table 7.2). The acceptability of this B12 source is still yet to be completely assessed but beginning studies have been conducted stating that consumers had a generally positive mindset towards duckweed as human food when seen in a fitting meal and upon informing consumers on the positive nutritional and environmental impacts the product has there was a decreased acceptability in non-fitting meals. Its individual or mixed components of methylcobalamin and hydroxocobalamin provided by most likely a symbiotic relationship thought to be due to photosynthetic eukaryotes (Kaplan et al., 2019). These two forms of vitamin B12 in the raw material can also be considered to have relatively the same degree of bioavailability as that of pure methylcobalamin powder (56–89%) (Obeid et al., 2015). Studies show that the bioavailability of intracellular methylating metabolites is determined based on individual metabolisms and single nucleotide polymorphisms rather than being dependent on the form itself. (Paul & Brady, 2017). Duckweed/Water lentils have a minimal carbon footprint, estimated at 0.4 kg CO_2/kg (De Beukelaar et al., 2019). Its high growth rate and its tolerance of extreme conditions as well as the ability for the materials cultivation in basins on non-arable land make it a highly sustainable product due to its lack of farmland needed and minimal control of general conditions. (De Beukelaar et al., 2019).

Milk is also a great source of B12, and it can be used to make things such as Greek yogurt. Milk itself contains methylcobalamin. Vitamin B12, in milk, is bound to very specific protein carriers such as transcobalamin and haptocorrin (Fedosov et al., 2019). These types of proteins improve the availability of B12 in milk. This is due to the pH stability and slow proteolysis which help the nutritional availability of B12 in the milk. (Fedosov et al., 2019). Milk itself delivers half of the RDI, in as little as 100 g (Matte et al., 2012; NIH, 2021h) (Table 7.2). Environmentally, it takes 1,020 litres of water to produce a litre of Greek yoghurt (Hayek et al., 2021). This is extremely unstainable, and leads to a great amount of water waste each year. There is also concern about the emissions that cows are putting into the environment, with a total of 3.0 kg CO_2/kg (Hayek et al., 2021). This is contributing heavily to the agriculture greenhouse gas emissions, which is contributing dramatically to climate change. The biological oxygen demand reaches around 6.9 and $48 gL^{-1}$, and the chemical oxygen demand reaches 12 and 95 g/L for dairy production (Fedosov et al., 2019). This is extremely detrimental to the health of the environment.

7.3.4 Vitamin C

Kiwifruit offers plenty of vitamin C: 69% of the RDI in a 100 g fruit (Dumbravă et al., 2016; NIH, 2021i) (Table 7.2). The absorption rate of vitamin C in the human body is related to the intake (Vissers et al., 2013). The absorption rate can reach 100% when the intake is 30–60 mg. When the intake is 90 mg, the absorption rate is reduced to about 80%. When the intake is 1,500 mg, the matching absorption rate is 49%. The body can only absorb 36% of nutrients when the intake is 3,000 mg, and when the absorption rate is 16%, the intake is 12,000 mg. The daily intake of vitamin C by adults is 100 mg, a kiwi fruit weighs about 160 g, and 100 g of kiwi fruit contains 62 mg of vitamins. Therefore, eating a kiwi fruit every day can supplement vitamin C for a day. But because vitamin C is easily destroyed regardless of whether it exists outside or inside the body. Although a large amount of ingestion is not harmful to the human body, it should not be taken too much at once, because after a large amount of ingestion, it will not all be absorbed, and the final result is still excreted from the body. The best way is to separate the time and use it in segments, so as to increase the absorption rate of vitamin C in the body (Vissers et al., 2013). Environmentally, it is a feather-like light touch: 80–100 L water are needed and 0.15–0.50 kg CO_2 are emitted per kg of kiwifruit harvested (Müller et al., 2015; Soyergin, 2016). It likes a cool and humid climate, with annual precipitation exceeding 800 mm and relative humidity exceeding 70%.

Blackcurrant products (beverages, freeze-dried powders) are relatively new to the market and slowly increasing in popularity (Ārepa, 2021; ViBeri, 2021). A study on the ascorbic acid content of freeze dried and air dried berries found that its levels were consistently higher in organically and sustainably grown crops compared to conventionally grown. It also found that both freeze-dried and air dried berries demonstrated a statistically significant decrease in vitamin C levels compared to frozen, but freeze dried was still better than air dried (Asami et al., 2003). The problem here is cost and sustainability. ViBeri's "New Zealand Organic Blackcurrant Berries" cost NZD 14.13/100 g. Moreover, freeze-drying involves large energy expenditures, carbon emissions and water waste, unless it is recycled. Ārepa also produces a freeze dried blackcurrant product, the "Freeze Dried Neuroberry". The Neuroberry product too costs a lot: NZD 23.3/100 g. The price issue can be overcome by the low serving size needed of about 10 g. Drying still represents a large environmental burden so alternative concentration techniques should be considered. The benefit is enhanced shelf-life and no need for cold storage (freezer or fridge). Blackcurrants have minimal impact, with only 500 L water required per kg harvested (Mekonnen & Hoekstra, 2010), while data on the carbon emissions was not found. This leaves some room for processing. Shelf-stable blackcurrant products could be a new sustainable way to Vitamin C, if more efficient technologies for water removal will be found.

7.4 Conclusions

Water soluble vitamins are a large group. Vitamins B1, B2, B3, B5, B6 and B7 are mostly found in wholegrains, but also diary and meat. Vitamins B9 and B12 often affect similar health mechanisms. While B9 (folate) is abundant in wholegrains, seafood and animal liver, B12 is prerogative of animal food (liver, dairy, eggs). Similarly, fruit and vegetables are prerogative for vitamin C. Innovative food products propose plant-based solutions for B vitamins based on nuts, pulses and defatted seeds. The last two are more sustainable than nuts, environmentally, requiring less water, while delivering similar, if not superior, nutritional benefits. Nonetheless, they are more challenging in terms of taste and texture. It is fascinating that B12 was found in a plant based sources (microalgae such as spirulina and duckweed) although research is new so further data must be collected to guarantee adequate supply. The extremely low carbon footprint of microalgae, due to their ability to sequester carbon, makes them interesting, when compared to Greek yoghurt, yet sensory challenges persist. Finally, vitamin C innovations are not as exciting, perhaps relying on a wide array of sustainable options, based on local produce.

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