Elżbieta WIERZBICKA, Ph.D
Department of Human Nutrition, Institute of Human Nutrition Sciences
Warsaw University of Life Sciences (SGGW-WULS), Poland
Katedra Żywienia Człowieka, Instytut Nauk o Żywieniu Człowieka
Szkoła Główna Gospodarstwa Wiejskiego w Warszawie, Polska

VITAMIN D FORTIFICATION IN DAIRY PRODUCTS – POSSIBILITIES TO IMPROVE VITAMIN D INTAKE®

Produkty mleczne wzbogacone w witaminę D – możliwości zwiększenia jej spożycia®

Key words: food fortification, vitamin D, dairy products.

This review presents vitamin D and its importance to the human body and issues related to the fortification of foods with vitamin D. Such foods may constitute an integral part of the daily diet and contribute to a health-promoting nutrition model. It is, therefore, imperative that foods fortified with vitamin D constitute part of a well-thought-out strategy to increase the intake of this deficient nutrient and, in the long term, help to balance the diet and thus improve vitamin D status. Increasing vitamin D intake should be considered a public health priority. Attention should be paid to fortified dairy products which can contribute to increasing vitamin D deficiency intake.

Słowa kluczowe*:* wzbogacanie żywności, witamina D, produkty mleczne.

W artykule przedstawiono witaminę D i jej znaczenie dla organizmu człowieka oraz zagadnienia związane ze wzbogacaniem żywności w witaminę D. Żywność tego typu może stanowić integralny element codziennej diety i wpisywać się w prozdrowotny model żywienia. Z tego względu konieczne jest aby żywność wzbogacona w witaminę D wpisywała się w dobrze przemyślaną strategię zwiększenia spożycia deficytowego składnika odżywczego i w działaniu długoterminowym pomagała w zbilansowaniu diety, a co za tym idzie poprawiała stan odżywienia witaminą D. Zwiększenie spożycia witaminy D należy uznać za priorytet zdrowia publicznego. Na uwagę zasługują fortyfikowane produkty mleczne, które mogą przyczynić się do zwiększenia spożycia deficytowej witaminy D.

INTRODUCTION

In recent years, there has been an increased interest in vitamin D and its supply from the diet, including the possibility of increasing its intake through the consumption of fortified foods. This interest is justified as its consumption from natural sources (oily fish) is considered low. Increasing the intake of this vitamin is the goal of various nutritional strategies, both in preventive programmes (use of supplements) and food production (fortification) [3, 7, 9, 14, 18, 27, 35, 42]. Increasing vitamin D intake should be considered a public health priority [9, 12, 14, 19, 23, 25, 30, 35].

As consumers become more interested in maintaining or improving their health, there is a growing demand for foods fortified with nutrients, including vitamin D [5, 9, 11, 14, 25, 42]. Dairy products stand out in this group. Not only does milk contain several essential nutrients necessary for growth, development and the maintenance of optimal health, but it is also considered an important staple food and can be used as a vehicle for the supply of other nutrients [4, 5, 7, 8, 10, 18, 27, 36, 41, 42]. Thus, it provides excellent opportunities for the food industry to use **milk and dairy products** as vehicles for vitamin D fortification [9, 14, 16, 21, 25, 26, 39, 40, 41, 44, 45]. Even if the natural content of vitamin D in cow's milk is low (0.1–1 µg/L in full fat milk) [15], the consumption of milk fortified with vitamin D has shown to be effective in improving the vitamin intake [5, 8, 10, 11, 12, 18, 20, 26, 27, 36, 39, 41, 45]. Improving vitamin D intake through food fortification represents an inexpensive intervention that can improve the health of the population [16, 21, 42, 44].

It is well known that there is vitamin D deficiency among the vast majority of the world's population [3, 17, 18], including in Poland [13, 22, 29, 35]. Its primary source is synthesis in the skin. Nowadays, the importance of cutaneous synthesis for the body's vitamin D supply is diminishing due to lifestyle changes and reduced sun exposure. Of all food products, oily fish is the richest source of vitamin D, however, its consumption beyond the Scandinavian countries and southern Europe is insufficient [3, 9, 14, 18, 27]. For vitamin D deficiency prevention, consideration is being given to fortifying more selected food products to which cholecalciferol or ergocalciferol is added during food processing. To address the challenge of low vitamin D intake, consideration should

Corresponding author – Adres do korespondencji: Elżbieta Wierzbicka, Department of Human Nutrition, Institute of Human Nutrition Sciences, University of Life Sciences (SGGW-WULS), 159c Nowoursynowska Street, 02-776 Warsaw, Poland, e-mail: elzbieta_wierzbicka@sggw.edu.pl

be given to identifying food groups that can contribute to increasing vitamin D intake [7, 9, 17, 18, 25, 27, 36, 42].

Low vitamin D status is a global public health issue and vitamin D food fortification may help to improve vitamin D intakes and status at the population level [3, 9, 11, 17, 23, 24]. Dairy products appear to be such a group [5, 10, 12, 14, 18, 20, 25, 26, 27].

This article aims to present the role and importance of vitamin D to the body, its level of occurrence in food and selected aspects of food fortification, with particular emphasis on the importance of dairy vitamin D-fortified products.

VITAMIN D IS IMPORTANT FOR HEALTH

Vitamin D is a fat-soluble vitamin that is essential for bone health and facilitating muscle function. Vitamin D plays a significant role in calcium and phosphate metabolism and prevents rickets in children and osteomalacia in adults (bone softening), or osteoporosis in adults (loss of bone density). Vitamin D deficiency is associated with muscle weakness and osteoporosis and can contribute to an increased risk of falls and fractures. Additionally, there is growing evidence suggesting a connection between vitamin D deficiency and non-skeletal health outcomes [2, 23, 28, 30].

Vitamin D belongs to the group of fat-soluble steroidal compounds, with two most essential forms: vitamin D3 (cholecalciferol) and vitamin D2 (ergocalciferol). Both vitamin D3 formed in the skin and vitamin D3 and D2 derived from dietary sources undergo a metabolic cycle in the body producing biologically active metabolites. The first hydroxylation step occurs in the liver by the vitamin D-25-hydroxylase (CYP2R1) to calcidiol (25-hydroxyvitamin D3 (25(OH)D) and the final hydroxylation step occurs in the renal proximal convoluted tubules by the vitamin D-1-hydroxylase (CYP27B1) [1, 2, 3, 18, 27]. Synthesis of the active form of vitamin D – 1,25$(OH)_2$D, occurs in the kidneys and other tissues, underpinning its systemic multidirectional pleiotropic action, with possible roles in diabetes, cancer, ischemic heart disease, and autoimmune and infectious diseases [2, 23, 28, 30, 35].

The most commonly used marker of vitamin D status is 25(OH)D that is measured in blood serum/plasma to determine vitamin D level because it shows vitamin D loading from dietary intake and sunlight exposure, as well as the conversion of vitamin D from fat stores in the liver. Vitamin D deficiency is defined as 25(OH)D < 50 nmol/L and vitamin D insufficiency is defined as 25(OH)D < 75 nmol/L [29, 30].

SOURCES OF VITAMIN D, CURRENT SITUATION, ISSUES AND CHALLENGES

Vitamin D belongs to the group of fat-soluble steroidal compounds, with two most essential forms: vitamin D3 (cholecalciferol) and vitamin D2 (ergocalciferol). D3 is obtained from the diet (through natural or fortified foods or supplementation) or it can be synthesised in the skin via the action of UVB radiation (290–315 nm). Vitamin D2 is derived from mushrooms and yeasts after UVB irradiation, the consumption of which is relatively low [3, 14, 18].

Synthesis of vitamin D following exposure of the skin to UVB radiation is the predominant source of the vitamin for most people in Poland during the summer months (May to September) [13, 22, 29, 30, 35]. Actual endogenous synthesis of vitamin D is also limited by climatic conditions and protective measures against skin cancer (sun avoidance, use of UV filter creams) [30, 35]. There are relatively few dietary sources of vitamin D3, the richest being oily fish and and fish liver oil, which are not commonly consumed in many diets [9, 14, 15, 25, 27]. Among foods, oily fish (eel, salmon, herring, mackerel) contain the highest amount of cholecalciferol, but their consumption in Poland is low and infrequent [13, 22, 35].

Other sources include egg yolks, meat products and also fortified foods, such as some dairy products (especially fluid milk, yogurts), some breakfast cereals, and fat spreads which provide a portion of the recommended intake of vitamin D [3, 7, 9, 18, 25]. High intake of meat and milk products is typical for a western diet and provides a contribution to the total vitamin D intake, however contributes lower content of vitamin D compared to fish. It is estimated that natural foods only cover about 20% of the daily vitamin D requirement [13].

Moreover, products fortified with vitamin D, i.e. those to which cholecalciferol or ergocalciferol are added during technological processes, can play a vital role in the supply of vitamin D. Dietary intake of vitamin D can be improved by fortified food products that are increasingly available on the market, e.g. some dairy products, margarines and spreadable fats, ready-to-eat breakfast cereals [3, 5, 8, 9, 10, 11, 12, 18, 20, 24, 25, 27, 36, 41, 42]. Except for infant formula and margarine, there is currently no mandatory fortification policy for vitamin D in the Poland, so voluntarily practice can vary considerably across the industry and manufacturers [7, 34, 43].

Dietary supplements are an additional concentrated source of vitamin D, intended to supplement the diet and reduce the risk of vitamin D deficiency. It is particularly relevant for at-risk groups who should take vitamin D supplements throughout the year. Other groups of the population are advised to supplement with vitamin D between October and March when exposure to sunlight does not ensure enough cutaneous synthesis [30, 35].

The results of studies on the evaluation of various forms of vitamin D indicate a preference for vitamin D3 (cholecalciferol) rather than vitamin D2 (ergocalciferol) in the prevention of vitamin D deficiency. Vitamin D3 appears to be more effective than vitamin D2 in raising serum 25-hydroxyvitamin D concentration, which has implications for the choice of a supplement [37].

Based on national and international research findings, dietary sources of vitamin D and its dermal synthesis are insufficient to provide the body with an adequate supply of this vitamin. Most of the population's average daily vitamin D intake is below the recommended dietary standard and does not ensure optimal levels of vitamin D (as measured by 25(OH)D serum levels) [3, 13, 19, 29].

With few natural dietary sources of vitamin D, food fortification and dietary supplements serve as important methods for ensuring a sufficient vitamin D intake of the population. Therefore, public health strategies addressing fortification, biofortification and supplementation are needed to ensure that current vitamin D targets are met [3, 5, 9, 14, 18, 25, 27, 30, 35, 36].

NUTRITIONAL RECOMMENDATIONS AND DIETARY INTAKE

According to the current dietary reference values [13], the requirements for vitamin D are set at the Adequate Intake (AI) level. The vitamin D intake of 15 µg/day represents the average adequate intake to achieve a serum 25(OH)D of ≥50 nmol/L. This target value is considered to cover the requirement of the majority of the population in relation to the optimal calcium absorption and related bone health [6, 13]. The EFSA recommend the upper daily limit below 100 µg/day (4000 IU) [6].

Numerous studies show an average vitamin D intake well below the recommended standard. In Europe, vitamin D intake is generally between 3 and 5 µg per day [4, 14, 18, 22] and even with values of 2.2 µg [17], with higher intakes in Northern Europe (up to 11–14 µg/day) [8, 10, 24]. In Poland, vitamin D intake is also well below the recommendations. Average daily intake is about 1,4–5,1 and 0,6–3,5 µg/day, respectively, in adults and children [13].

The deficient intake of vitamin D in the Polish population is reported in several studies, with attention drawn to the high prevalence of vitamin D deficiency in winter when sun-induced vitamin D synthesis is insufficient [22, 29, 30, 35]. It should be noted that an important source of vitamin D is supplementation. In Poland, vitamin D is routinely prescribed to infants and young children. Further supplementation for age-school children, as well as for adults, is advised based on official recommendations [30, 35].

However, given the increasing popularity of supplements and their uncontrolled use, such intervention entails the risk of exceeding the upper tolerable intake level. Excess intake of vitamin D in the form of pharmaceutical preparations and/or supplements leads to hypervitaminosis [6, 38].

Moreover, many peoples don't consume milk (and other fortified foods) meaning that vulnerable subgroups, such as those with low milk consumption for a variety of cultural and other reasons, are at risk of vitamin D deficiency [4, 18].

Given that the majority of Poles consume less than the currently recommended intake of vitamin D from food [13], consideration should be given to strategies to improve vitamin D intake by increasing both the amount of vitamin D added to foods and the range of foods eligible for fortification [7].

To improve the vitamin D status at population level, food fortification, dietary supplementation and public education all need to be considered as practical strategies to be pursued [3, 9, 18, 25, 27, 30, 35, 42]. Additionally, adults who want to ensure a sufficient vitamin D status as well as certain risk groups may require additional consideration in terms of addressing low vitamin D status by dietary supplementation, with the aim to reach the target levels of 30 to 50 ng/mL (75 to 125 nmol/L) [30, 35].

EU FORTIFIED FOODS REGULATION

Fortification of food refers to the adding of nutrients, most commonly one or several vitamins and/or minerals, to food in connection with the production process.

Relevant legislation addressing fortified foods:

- Regulation (EC) No. 1925/2006 of the European Parliament and of the Council on the addition of vitamins and minerals and of certain other substances to foods: Annex I – Vitamins and minerals which may be added to foods; Annex II – Vitamin formulations and mineral substances which may be added to foods; Annex III - Substances whose use in foods is prohibited [31].
- Regulation (EC) No. 1924/2006 of the European Parliament and of the Council on nutrition and health claims made on foods [32].
- Regulation (EU) No. 1169/2011 of the European Parliament and of the Council on the provision of food information to consumers [33].

FOOD FORTIFICATION TO INCREASE VITAMIN D INTAKE – OPPORTUNITIES FOR THE FOOD INDUSTRY

In addition to adhering to a balanced diet, it is clear that alternative food-based strategies are required to help the consumers meet the dietary recommendations for vitamin D [3, 14, 18, 25, 27, 42]. Endogenous synthesis is only possible during spring and summer at Poland's latitude; during autumn and winter in Poland, vitamin D has to be obtained exclusively from the diet (including food fortification and vitamin D supplements) [22, 29, 30, 35].

Three potential strategies for addressing poor micronutrient intakes have been identified by the WHO/FAO: (1) increasing the diversity of foods consumed, (2) food fortification, and (3) supplementation [42]. Also, the valuable contribution that fortified milk makes to vitamin D intakes among consumers has been acknowledged [8, 10, 11, 12, 14, 18, 20, 24, 25, 26, 27, 36, 39, 41, 42, 44, 45].

There is increasing evidence to support the role of vitamin D food fortification in maintaining or improving the vitamin D status. It is essential that the fortification is of mass coverage and that the additive is added to commonly consumed foods, such as various fluid milk and other dairy products [18, 25, 27, 42]. Mandatory fortification of staple foods offers the greatest benefits to public health, through an improved diet which includes vitamin D-fortified foods and having a bigger impact at the population level [10, 11, 27, 36].

As defined by FAO/WHO Experts, food fortification is the addition of one or more nutrients to selected products, whether or not they occur naturally in that product. The overarching aim of food fortification is to prevent and remedy existing deficiencies of one or more nutrients in entire populations or specific population groups [42]. A distinction is made between the following types of fortification: compensatory restoration, used to make up for losses; intervention, aimed at preventing deficiencies of a particular nutrient; and enhancement, used to

improve the nutritional value and attractiveness of a product and to make it more like its natural counterpart [42].

Several rules and regulations define the extent and quantities of substances that can be added to food. In the case of vitamin D, the two major forms: cholecalciferol (vitamin D3) and ergocalciferol (vitamin D2) are added to foodstuffs [31, 34]. Vitamin D fortification policies for food are presented in Table 1.

Table 1. Vitamin D fortification policies in selected European countries

Tabela 1. Wzbogacanie żywności w witaminę D w wybranych krajach europejskich

Country	Fortification policy
Austria	No mandatory fortification
Belgium	Mandatory: Margarines and spreadable fats Voluntary: milk, dairy drinks, plant-based beverages
Czech Republic	No mandatory fortification
Finland	Mass fortification of milk, margarine/fat spread; Voluntary: yoghurt, plant-based substitute, bread, cereals
France	No mandatory fortification
Germany	No mandatory fortification
Greece	No fortification policy
Iceland	Low-fat milk, some imported foods (vegetable oils and cereals)
Ireland	Mandatory: margarine Voluntary: milk, cereals
The Netherlands	No mandatory fortification; Voluntary fortification: only for certain fats and oils, dairy products
Norway	Voluntary: low-fat milk
Switzerland	No mandatory fortification
Sweden	Low-fat milk, fermented milk products, margarine
UK	Margarine, bread, cereals

Source: On study based on: [23]

Źródło: Opracowanie własne na podst.: [23]

Furthermore, besides the documents shared by the European Union countries, each country has its own regulations. Poland also has relevant acts regulating vitamin D fortification in this scope. Only fortification with vitamin D of normal and reduced-fat margarine (maximum amount not exceeding 7.5 µg/100 g) [34] and infant formula, as well as modified milk for children is mandatory. Other foods can be fortified with vitamin D on a voluntary basis, including e.g. cow's milk and dairy products, substitutes of plant origin, instant cocoa drinks and breakfast cereals [7].

Following an evaluation of voluntarily vitamin D-fortified products on the Polish market, it was shown that they differ significantly in terms of energy and nutritional value. Based on an analysis of the range of these products, it was estimated that the implementation of fortified products such as milk, yoghurt, sugar-free cereals and fruit juice into the diet resulted in a 3.0-fold increase in vitamin D content. In contrast, replacing non-fortified products with fortified products such as flavoured milk, breakfast cereals and other cereal products resulted in a 3.5-fold increase in dietary vitamin D content, with a significant increase in added sugars, including a 2-fold increase in sucrose [43]. There is concern that consumption of foods slated for voluntary fortification would ultimately be associated with higher intakes of sugars and/or saturated fatty acids as well as suboptimal food-intake patterns, it is necessary to recommend vitamin D-fortified products with health-promoting properties of foods, i.e. low in added sugars, salt and/or saturated fatty acids [7, 43].

In addition to naturally occurring vitamin D, its content can be increased during production through biofortification. Addition of vitamin D to the food products by fortification (direct addition to food) or biofortification (e.g. addition to animal feed or UVB irradiance of animals or produce) may be appropriate strategies to improve vitamin D intakes [3, 5, 14, 18, 27]. The addition of vitamin D to food is effective in improving circulating 25(OH)D concentrations using many food vehicles; the effect on vitamin D status was greater when baseline 25(OH)D concentrations were <50 nmol/L and when the fortification dose was ≥10 µg/d [5].

VITAMIN D FORTIFICATION OF DAIRY PRODUCTS – EXAMPLES OF PRACTICES

Milk has been widely used as a vehicle for vitamin D fortification because it is a staple food with good implementation and acceptance by the population. Table 2 shows the various techniques used to fortify milk with vitamin D. Encapsulation seems to be an indispensable tool to design vitamin D materials with the desired functionality to deliver vitamin D through beverages, with advantages over the direct addition and emulsification approaches [21, 40].

Vitamin D fortification was initially used in cow's milk to prevent rickets. Today, in addition to liquid milk, other foods are used as a vehicle for the enrichment substance. The term fortification usually describes the process by which D_3 or D_2 is added during food processing [7, 16, 18, 21, 27, 40, 41, 42, 44, 45].

Vitamin D fortification can be a voluntary or mandatory practice. Only a few countries (e.g. Finland, Canada, and the US), have introduced regulated milk fortification to increase dietary vitamin D intake [10, 11, 12, 18, 27]. Examples of vitamin D fortification of milk and dairy products are shown in Table 3.

Fortified milk products have been an important source of vitamin D and a major dietary determinant of serum 25(OH) D in countries with national fortification policy, such as e.g. Finland, Canada and the US, whereas their role has been smaller in countries where fortification is not mandatory, such as in Sweden and Norway [10, 11, 27, 36]. In most European countries there is no mandatory fortification of milk and dairy products (except for infant formulae and follow-up milks) [18].

Table 2. Fortification approaches of vitamin D-fortified dairy products

Tabela 2. Przykłady wzbogacania produktów mlecznych w witaminę D

Products / Formulation	Fortification level IU (40 IU= 1 µg)	Vitamin Stability	Sensory Properties
HTST 2% fat milk /Water dispersible Vit D3	250 IU / 240 mL	Tolerate HTST No loss of Vit D3 during storage at 4°C	No significant changes in composition and sensory attributes
UHT 2% fat chocolate milk / Water dispersible Vit D3	100 IU / 240 mL	Tolerate UHT No loss of Vit D3 during storage at 4°C	No significant changes in composition and sensory attributes
Milk / Vit D3 Spray Drying	600 IU or 1000 IU/200 mL	Stability loss <10% after 12 weeks of storage period	NE
UHT 3% and 8.5% fat milk / Vit D2-protein complexes	500 IU/L	Higher stability during storage at -20°C, followed by 4°C and 37°C	NE
Milk / vit D2 - encapsulation	600 IU/L	Stable during pasteurization, boiling, sterilization, packaging, and storage conditions	NE
Milk-based beverage (Indian origin) / Vit D3-nanostructured lipid carrier	400 IU/100 mL	High physicochemical stability against temperature, ionic strength and pH	No significant changes in composition and sensory attributes

Legend: ND – not defined; NE – not evaluated
Legenda: ND – niezdefiniowane, NE – niemierzalne

Source: On study based on: [21, 40]

Źródło: Opracowanie własne na podst.: [21, 40]

Table 3. Examples of vitamin D-fortified dairy products

Tabela 3. Produkty mleczne wzbogacone w witaminę D

	Dairy products	Fortification level µg (1 µg= 40 IU)	Food serving
Finland	Fluid cow's milk*	2.5	250 ml or 1 cup
	Yogurt	0.5 – 1.0	per 100 g
United States	Fluid cow's milk*	2.5 – 5.0	250 ml or 1 cup
	Yogurt	1.5 – 5.0	per 170 g
	Cheese	1.5	slice (16 g)
Canada	Fluid cow's milk*	2.5 – 5.0	250 ml or 1 cup
	Yogurt	1.0	per 100 g

*Mass fortification (usually mandatory)

*Fortyfikacja masowa (obligatoryjna)

Source: On study based on: [10, 27]

Źródło: Opracowanie własne na podst.: [10, 27]

Food enrichment increases the intake of deficient nutrients and helps balance the diet. It is an effective method for large population groups, but it must be a long-term measure to be effective. Vitamin D enrichment of foods (mandatory or voluntary based on national recommendations) is currently used in a few European countries [10, 11, 12] and some North American countries [36]. The amount of added vitamin D varies in these countries, as do the food matrices [16].

Milk and dairy products are considered a suitable matrix for vitamin D enrichment [3, 9, 10, 16, 18, 21, 41]. Natural vitamin D concentrations in whole milk ranges from 0.34 to 0.84 IU/g of fat and unfortified milk is not a significant source of this vitamin D. Fortified milk and dairy products are one of the most frequently used sources of vitamin D [40, 44, 45].

Some countries have a mandatory milk enrichment policy. The recent results of the meta-analysis provide evidence of the need to enrich foods with vitamin D. Based on these results, the authors conclude that systematic supplementation and food enrichment can significantly reduce cancer mortality in Europe [23]. While some European countries have already introduced widespread vitamin D enrichment in foods, in others, only a few foods are enriched or not enriched at all [23].

It should be noted that currently the extent of food fortification varies between countries and coverage is not universal, implying that these products do not significantly supplement vitamin D supply, save for infant and young children's formulas, where fortification is mandatory [9, 27]. Bearing in mind the results of recent studies, the preferred strategy for improving vitamin D status is food enrichment at the population level, provided that sufficient monitoring is carried out and population groups are defined [4, 8, 9, 10, 11, 12, 36]. Milk, yoghurt and other dairy products are indicated as an important product group where enrichment could be at a level of approximately 0.1 µg/100 g [10, 11, 18, 27].

Other options, such as biofortification of food products of animal origin like eggs and farmed fish, may also be considered as additional ways to increase vitamin D intake in the population [14]. Meat, on the other hand, should be carefully considered as an additional way to increase vitamin D intake in the population [7, 13].

It should also be stressed that the problem of restricting milk enrichment is also related to the fact that not everyone in the population consumes milk (e.g. due to lactose intolerance) while the idea of compulsory enrichment is to protect the

general population. Thus, the preferred enrichment approach may be adding vitamin D to other foods, which may also lead to improved vitamin D nutritional status [4].

An excellent example of an effective strategy is the vitamin D3 enrichment of liquid milk (1 µg/100 g) and margarine and fat spreads (20 µg/100 g), as confirmed by an 11-year Finnish study assessing the vitamin D status of different groups of the country's population. It was shown that the concentration of 25(OH)D levels in the blood increased from 48 to 65 mmol/l, and the prevalence of deficiency, assessed as 25(OH)D<30 nmol/l, decreased from 12 to 1 per cent of the studied subjects. Fluid milk products' contribution to dietary vitamin D intake changed from 4 to 34% in the same period [Jääskeläinen,2018]. Similar beneficial effects of the introduced nutritional intervention of a diet containing 20 µg/day of vitamin D, which included the following fortified products, i.e. yoghurt, cheese, eggs and bread, were also reported in a study of women in Denmark. After the 12-week intervention, there was a statistically significant increase in 25(OH)D concentrations and a reduction in the proportion of people deficient in this vitamin D to 3% compared to a control group of 23% [8].

Increasing vitamin D intake is possible through an adequate diet with the inclusion of fortified products and additional sources in the form of dietary supplements. Nevertheless, given the increasing popularity of supplements and their uncontrolled use, such intervention risks exceeding the upper tolerable intake level. Excess intake of vitamin D in the form of pharmaceutical preparations leads to hypervitaminosis. Symptoms include hypercalcaemia, hypercalciuria with risk of renal tubular damage and renal stone formation, and increased calcium deposition in certain soft tissues and blood vessels. The cases of hypervitaminosis D described in the literature were mainly due to mistaken or unintentional administration of high doses of vitamin D preparations [38]. Therefore, in line with national recommendations for optimal prevention of vitamin D deficiency and increased vitamin D intake, it is advisable to act on a population-wide and individual level [9, 18, 27, 42].

The enrichment ingredient should be assimilable, evenly distributed, and unchanged during transport, storage, and cooking. The addition of an enrichment ingredient must not impair the organoleptic characteristics or increase the price of the product. The doses used should be sufficient to achieve the intended effect, but not pose a risk of overdose or antagonistic interaction with other nutrients [7, 16, 38, 42]. The ingredient should be listed in the product formulation and its content indicated in the nutritional information on the packaging [33]. Only specific enrichment substances can be used for fortification [7, 32, 42]. In general, the choice of carrier is up to the food producers, and the purchase decisions are up to the end consumers [39].

The choice of milk and dairy products as a vehicle for enrichment is also supported by other meta-analysis results [1], which confirmed a favourable association between dairy consumption and a lower risk of type 2 diabetes. Dairy product consumption (total) was shown to be associated with a significantly lower risk of T2D (RR: 0.81-0.83), particularly for the consumption of low-fat dairy products (RR: 0.82), and yogurt (RR: 0.74-0.86). In contrast, no such relationship was found for high-fat dairy. In these studies, the relationship was quantified, where the risk of type 2 diabetes is reduced by each unit increase in intake of dairy products (total) (200-400 g/d) or low-fat dairy products (200 g/d) [1].

A dietary modelling analysis has been performed to explore the potential effect of the fortified cows' milk of all types (whole, semi-skimmed, skimmed and 1% milks) with 1, 1.5 and 2 µg vitamin D/100 g. Baseline intakes were estimated to increase from 2.0 µg/day to 4.2, 5.1 and 5.9 µg/day, respectively. At the highest level (2 µg/100 g), the proportion of the population meeting the dietary recommendations would increase to just over 12% (from <1%) and the greatest impact was apparent in children [41].

A recent meta-analysis evaluated evidence that vitamin D-fortified products (dairy product, juice, grain product, oil and combination of dairy and grain products) can be a suitable solution for tackling vitamin D deficiency; an average of 2 nmol/l increase in 25(OH)D concentration for each 100 IU vitamin D intake per day is expected for general adult population [24].

While milk and dairy products are fortified with vitamin D, either mandatorily or optionally, their total contribution to vitamin D consumption and status is still unknown [16]. In observational studies, vitamin D-fortified fluid milk (ordinary milk and fermented items) contributed to higher vitamin D consumption and 25(OH)D status [10, 11, 12, 24, 25, 36, 41].

The fortification of cow's milk with vitamin D is strongly recommended by some governments as it represents a good vehicle for vitamin D, able to provide a small but significant amount of vitamin D, contributing to reaching the adequate daily intake [26].

In particular, the fortification of milk is recommended in Finland (1 µg/100 g in milk, yogurt and sour milk), while in Sweden fortification is mandatory for milk with a fat content below 3% (0.38–0.50 µg/100 g), and a similar approach is being adopted in Canada (0.825–1.125 µg/100 g) [10, 25, 36].

The safety of consumption of vitamin D-fortified foods has been confirmed by EFSA. Data from surveys carried out in European countries indicate that vitamin D intakes from all sources, including fortified foods, within commonly consumed diets, are far below the ULs for both adults and children [6]. Fortification of foods is the preferred strategy to increase the vitamin D intake. Milk, yogurt and other milk products should be fortified with around 10 µg/L (400 IU/L) [18].

SUMMARY

1. Increasing vitamin D intake should be considered a public health priority. To improve the vitamin D supply, the following course of action is recommended:
   - Increase dietary variety and consumption from natural sources (oily fish), and also intake of vitamin D-enriched foods, with particular attention to milk and dairy products, as well as consumption of foods naturally rich in vitamin D. When selecting additionally fortified products, the amount of other ingredients (e.g. simple sugars, fats) limited by current dietary recommendations should be taken into consideration.
   - Increase safe sun exposure during the summer months,

which is an endogenous source of vitamin D. It is worth noting that from October to March cutaneous synthesis is practically non-existent and, therefore, an appropriate vitamin D supplementation is then necessary.

- If vitamin D status is insufficient, it is advisable to implement regular supplementation with recommended doses, particularly in late autumn and winter months. These recommendations should be undertaken along with other dietary recommendations.

2. Addition of vitamin D to the dairy products by fortification, especially milk and other dairy products (in particular fermented) may be appropriate strategies to improve vitamin D intakes and status at the population level.

PODSUMOWANIE

1. Zwiększenie spożycia witaminy D należy uznać za priorytet zdrowia publicznego. W celu poprawy stanu zaopatrzenia organizmu w witaminę D, rekomendowane jest:
   - Zwiększenie urozmaicenia diety oraz spożycia tłustych ryb morskich, a także spożywania żywności wzbogaconej w witaminę D, ze szczególnym uwzględnianiem mleka i przetworów mlecznych, a także spożywania żywności naturalnie bogatej w witaminę D. Przy wyborze produktów wzbogaconych dodatkowo należy mieć na uwadze ilość innych składników (np. cukrów prostych, tłuszczów) limitowanych aktualnymi zaleceniami żywieniowymi.
   - Zwiększenie bezpiecznej ekspozycji na słońce w miesiącach letnich, stanowiącej endogenne źródło witaminy D. Należy zaznaczyć, że od października do marca synteza skórna praktycznie nie zachodzi i wtedy konieczna jest profilaktyczna suplementacja witaminą D.
   - W przypadku niewystarczającego spożycia witaminy D zalecane jest uzupełnienie w formie suplementów diety, zwłaszcza w okresie późnojesiennym i zimowym. Suplementację witaminą D należy prowadzać razem z innymi zaleceniami żywieniowymi.
2. Wzbogacanie produktów mlecznych, zwłaszcza mleka i innych przetworów (szczególnie fermentowanych) może być odpowiednią strategią poprawy spożycia witaminy D, a także stanu zaopatrzenia organizmu na poziomie populacyjnym.

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