Dairy Matrix in relation to Environmental Impact

How do we best evaluate Milk from a Health and Environmental Perspective?

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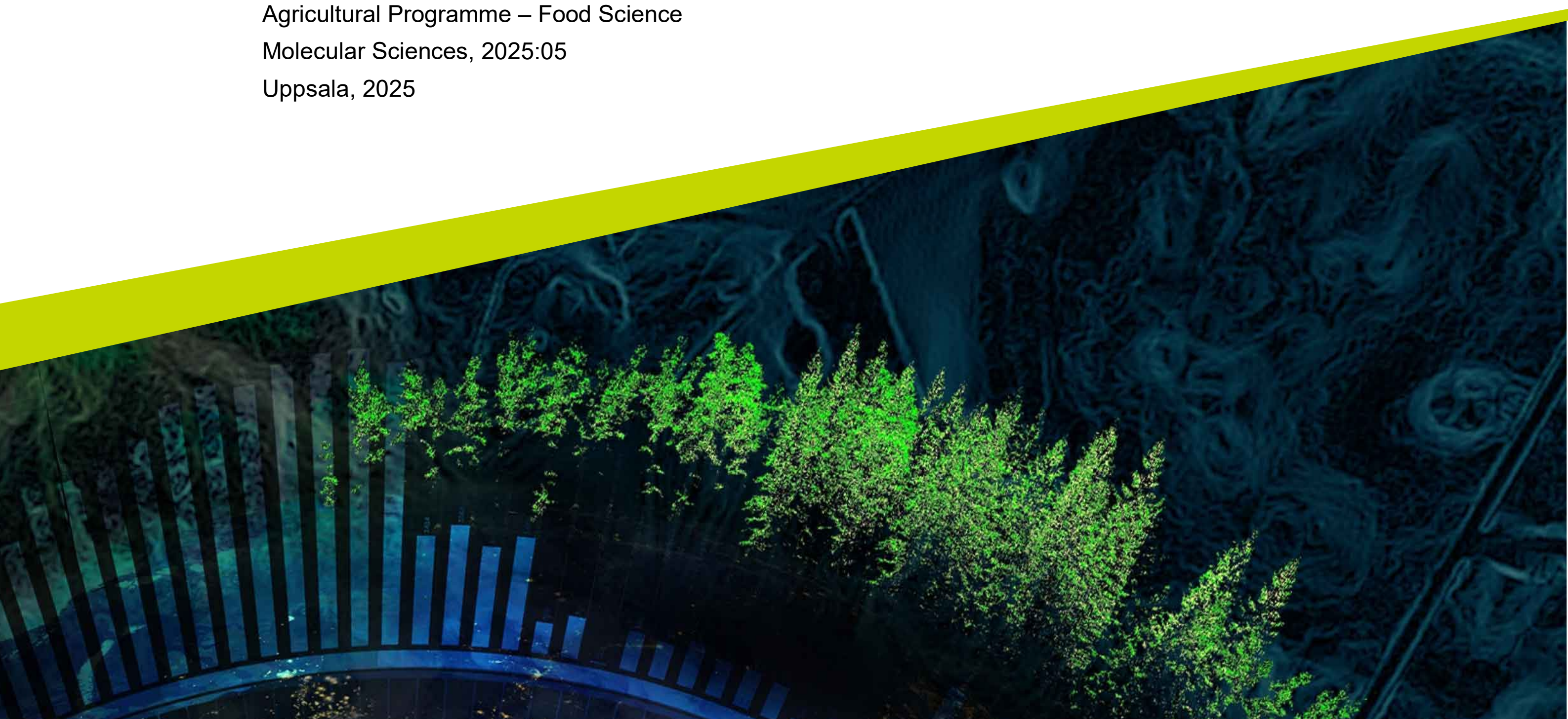

Dairy Matrix in relation to Environmental Impact – How do we best evaluate Milk from a Health and Environmental Perspective?

Mejerimatrisen i relation till miljöpåverkan – Hur utvärderar vi bäst mjölk ur ett hälso- och miljöperspektiv?

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Abstract

Milk is a food product that impacts both human health and the environment. Due to its widespread global consumption, it is highly relevant to investigate the relationship between these two aspects. The aim of this qualitative literature review is to provide a current analysis of research on the significance of the Dairy Matrix from both a health and environmental perspective, and to explore the relationship between them. The Dairy Matrix refers to the overall composition, structure, and interactions within milk and dairy products, taking a holistic view rather than focusing on isolated nutrients. Milk contains high amounts of saturated fat, which appears to negatively affect cardiovascular health. However, it also includes ruminant trans fatty acids and other short-chain fatty acids that have shown positive effects on human health. Additionally, milk contains bioactive peptides with anti-inflammatory and antioxidant properties. From an environmental perspective, milk production and consumption contribute to greenhouse gas emissions such as methane, carbon dioxide, and nitrous oxide. This is a concern, as increased emissions drive rising global temperatures with devastating effects on life on Earth. On the other hand, milk production has been shown to play a role in carbon sequestration in soil and in promoting biodiversity. There currently appear to be no established methods for jointly assessing the health and environmental impacts of milk. However, recent research suggests that it may be possible to find a balance in milk consumption that considers both health benefits and environmental sustainability.

Keywords: *Dairy Matrix, Milk Health, Milk Production, GHGE, Bioactive Peptides in milk, GMP, MFGM, Carbon sequestration, Biodiversity, Bioavailability of milk*

Sammanfattning

Mjölk är en livsmedelsprodukt som påverkar både människors hälsa och miljön. På grund av dess utbredda globala konsumtion är det mycket relevant att undersöka sambandet mellan dessa två aspekter. Syftet med denna kvalitativa litteraturöversikt är att ge en aktuell analys av forskning om betydelsen av mejerimatrisen ur både ett hälso- och miljöperspektiv, och att utforska sambandet mellan dem. Mejerimatrisen hänvisar till den övergripande sammansättningen, strukturen och interaktionerna inom mjölk och mejeriprodukter, med en helhetssyn snarare än att fokusera på isolerade näringsämnen. Mjölk innehåller höga halter mättat fett, vilket verkar påverka hjärt-kärlhälsan negativt. Den inkluderar dock även transfettsyror från idisslare och andra kortkedjiga fettsyror som har visat positiva effekter på människors hälsa. Dessutom innehåller mjölk bioaktiva peptider med antiinflammatoriska och antioxidativa egenskaper. Ur ett miljöperspektiv bidrar mjölkproduktion och konsumtion till utsläpp av växthusgaser som metan, koldioxid och lustgas. Detta är problematiskt, eftersom ökade utsläpp driver stigande globala temperaturer med förödande effekter på livet på jorden. Å andra sidan har mjölkproduktion visat sig spela en roll i kolbindning i marken och i att främja den biologisk mångfalden. Det verkar för närvarande inte finnas några etablerade metoder för att gemensamt bedöma mjölkens hälso- och miljöpåverkan. Ny forskning tyder dock på att det kan vara möjligt att hitta en balans i mjölkkonsumtionen som tar hänsyn till både hälsofördelar och miljömässig hållbarhet.

Nyckelord: Mejerimatris, Mjölkhälsa, Mjölkproduktion, Växthusgaser, Bioaktiva peptider i mjölk, GMP, MFGM, Kolbindning, Biologisk mångfald, Mjölkens biotillgänglighet

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Abbreviations

Abbreviation	Description
GHGE	Green house gas emissions
MFGM	Milk fat globule membrane
NNR	Nordic Nutrition Recommendations
TAG	Triacylglycerols
CVD	Cardiovascular Disease
fPDF	Femto- Potentially Disappeared Fraction
HDL	High Density Lipoprotein
LDL	Low Density Lipoprotein

1. Introduction

The introduction of this theses presents the background regarding Milk and various dairy products as well as their impact on health – and environmental impact. Furthermore, the purpose and research question are formulated and presented. Lastly, deliminations of the current study are presented.

1.1 Background

What we eat affects not only our health but also our planet. Today, both are threatened by the food choices we make (Willet et al. 2019). Our current food system is not sustainable and the world's population is both underfed and overfed. At the same time, the risk of not achieving many of the UN's 17 Sustainable Development Goals by 2030 is high (ibid). The 17 goals are based on the three dimensions of sustainable development; which are economic, environmental and social. The agreement includes all 193 member states of the UN, including Sweden. Two examples of the goals are (12) sustainable production and consumption and (13) combating climate change, which can be linked to our food system (Swedish UN Association n.d). The *Paris Agreement* is another climate agreement that Sweden, among others, is a part of. The main goal is to limit GHGE and thus keep the global temperature increase below 2 degrees Celsius and counteract global warming (European Council 2025).

In 2021, it was estimated that 39% of the world population was overweight or obese, while 9% was underweight (WHO 2023). These values depend a lot on our diet. The intensification of food, globalization and higher incomes are all contributing factors to a more homogenized dietary pattern while shifting towards a more "Western" diet consisting of, among other things, relatively high consumption of animal products where milk and other dairy products are included (ibid).

1.1.1 Composition of Cow's Milk

The content of milk varies depending on factors such as breeding, feeding strategies, season and lactation stage. For example, the fat content is usually higher in *Bos indicus* than *B. taurus cattle*. The fat content of milk from B. indicus cattle can be as much as 5.5 % (FAO 2025).

On average however, milk contains approximately 90% water, as well as lactose, fat, protein and most minerals and vitamins. The primary carbohydrate is lactose (4.6%) and is a reduced disaccharide of galactose and glucose linked by a b1à4 glycosidic bond (Jelen 2022).

Milk fat is a significant source of energy and is the carrier of the fat-soluble vitamins (A, D, E and K) and beta-carotene. Triacylglycerol (TAG) accounts for more than 95% of the lipid fraction. The remaining lipids include diacylglycerols, phospholipids, cholesterol and free fatty acids. Milk contains a total of about 400 different fatty acids with different lengths and saturation. Palmitic acid (16:0) and formic acid (14:0) are two examples of saturated fatty acids with a large proportion in milk and dairy products (Månsson 2008).

Furthermore, about 3.4% is comprised of proteins. They are divided into caseins and whey proteins. Caseins constitute 80% of the total content and include αs1-casein, αs2-casein, β-casein and κ-casein. The remaining 20% consists of whey proteins which include β-lactoglobulin, α-lactalbumin, serum albumin and immunoglobulins. Whey proteins are usually globular and soluble in the milk serum (Haug et al. 2007).

Milk naturally contains the fat-soluble vitamins and the water-soluble B-vitamins. It also contains many minerals such as calcium, potassium, phosphorus, selenium, magnesium, etc. (Livsmedelsverket 2023).

1.1.2 Milk and its effect on Health and Environment

The largest greenhouse gas emissions in the food sector come from livestock production, including red meat and dairy. In addition to the extensive use of grasslands that meat production requires, cows and sheep release methane gas through their digestion. At the same time, biodiversity and grazing are related to positive environmental impact.

Animal agriculture is also associated with both health benefits and disadvantages. There is strong evidence that high consumption of processed and red meat has negative effects on individuals' health. However, the evidence differs when it comes to dairy products and many studies have not found any significant link to negative health impacts (UN 2023). On the contrary, the Swedish Food Agency and other authorities recommend a daily intake of milk for adults to meet the daily dietary needs for calcium, vitamin B12 and iodine (Livsmedelsverket 2025).

In June 2023, the new Nordic Nutritional Recommendations were published. For the first time, the environment and what is sustainable to consume from both a health and environmental perspective were included. Among most food groups, there was an agreement between a healthy and an environment-friendly diet. For milk and dairy products, there seemed to be a conflict between health recommendations and climate impact (Blomhoff et al. 2023).

We have over the past 10,000 years not only domesticated animals for milk production but also transformed dairy into a global dietary staple. Today, over six billion people consume dairy in some form, and global production exceeds 900 million tons annually (WWF 2019). There are therefore many studies investatiging the health effects and environmental impact of milk. However, research showing the connection between health and the environment is limited and no clear mapping of the literature has been done.

1.2 Purpose & Research Question

The purpose of this study is to investingate and examine the environmental impact of milk and relate this to their potential health benefits according to the Dairy Matrix concept. By weighing these factors against each other, the study aims to contribute to a more nuanced picture of the role of milk consumption in a sustainable and healthy diet. The research questions for this study is:

- *How can a balance between environmental concerns and health benefits be achieved when consuming milk?*

1.3 Delimitations

The purpose of this report was to investigate milk as part of the dairy matrix from a health and environmental perspective. The study mentioned other various dairy products but they are all derived from milk. Milk has a complex composition and their interaction affects human health when consumed. However, the results mostly presented findings on milk fat, proteins and bioactive compounds. It was then linked to the environmental impact of milk. This part included aspects such as GHGE, biodiversity and carbon sequestration. No consideration was taken of, for example, water use due to limited research.

2. Methodology

2.1 Qualitative Literature Study

This report studies a relatively new and complex phenomenon, the Dairy Matrix, where it is not yet completely clear how calculations within the subject can be used. Therefore, a qualitative literature study was conducted. This type of study is characterized by the use of words and patterns to achieve findings that develop the form of the theory (Bell et al. 2019). It is common to use qualitative research when information is hard and extensive to quantify. The two databases Google Scholar and Pubmed were used during the work to create breadth in the search.

Several figures and tables have been used in this report. All creators have either given permission to freely use their illustrations as long as they are cited. In some cases, copyright-free illustrations have been used.

2.2 Search Strategy

The articles in these databases are all scientifically reviewed, credible and deal with topics in both medicine and environmental sciences. First, a pilot search was conducted with a few keywords such as *Dairy Matrix, Milk health, Milk Environment* in order to form an opinion about existing scientific articles that corresponded to the purpose of the literature study. This has then been supplemented by sources from authorities such as the Swedish Board of Agriculture, the International Dairy Federation and the National Research Council of Sweden, which all follow the development of research and update information based on it.

Publication year was not taken into account because findings from older studies may be accurate to this day. If there has been older statements which are no longer applicable, it has been addressed in the results. Furthermore, some geographical limitation were made to the extent that it has been possible. The primary focus has been on Nordic studies, especially when it comes to the environmental effects on milk production and consumption. This is because production methods and thus also environmental impact differ depending on the country of production. European or Nordic studies have been most relevant in this report. However, it has been difficult to geographically limit the searches on the health effects of milk from a Dairy-matrix perspective because European and Nordic studies are limited.

3. Results

In this section, the concept of Dairy Matrix is introduced. Thereafter, the results of this theses which consists of a review of scientific articles are presented . By showing the findings, the purpose of this section is to highlight milk as a whole rather than a sum of parts. The link between health and environmental impact is also brought to light in the results.

3.1 The Concept of Dairy Matrix

It is important to consider the greater sum of a product rather than only individual nutrients. Milk and other dairy products contain many nutrients but also other substances. Their interaction and the structures they form leads to the so-called *Dairy Matrix*. In the literature, the *dairy matrix* is defined in different ways and it does not seem to be used to a greater extent within a specific scientific framework.To balance the complexity of the concept and its practical application, expert members of the *International Dairy Federation* have created two definitions:

- *"The dairy matrix describes the unique structure of a dairy product, its components and how they interact".*
- *"The health effects of the dairy matrix refer to the impact a dairy product has on health that extends beyond its individual components".*

Within the dairy matrix, different structural levels can be identified, which are; molecular level which refers to, among other things, the primary, secondary, tertiary and quaternary structure of proteins, microscopic level and macroscopic level such as texture. The unique variations in structure and interactions create defined matrices that nuance the kinetics and extent of nutrient degradation, which in turn affects physiological responses (Mulet-Cabero et al. 2024).

3.1.1 Milk Peptides and Bioactive Compounds

Bovine milk is a natural source of bioactive compounds. These include lactoferrin, immunoglobulins, hormones and lysozyme (Lin et al. 2021). Native proteins can also be hydrolysed into functional peptides. They are often inactive within the primary structure of protein and are generated during proteolysis of casein and whey proteins. There are several studies that show a connection between milk peptides and a lowering effect on blood pressure by, among other things, binding to minerals (Cordova-Davalos et al. 2019) and inhibiting ACE, which is a natural enzyme that produces the hormone angiostenin II. This hormone then constricts blood vessels and raises blood plessure (Guo et al 2019).

Glycomacropeptide (GMP) is another example of a milk-derived bioactive peptide. It is released and hydrolyzed from kappa-casein by enzymatic digestion.

GMP is known for its numerous health benefits, including antibacterial, prebiotic, and remineralizing effects, as well as its roles in supporting digestion and metabolism, and its potential anti-tumor properties (Cordova-Davalos et al. 2019). It’s rich content of branched-chain amino acids have also been well studied. BCAA, and specifically leucine, are important in protein catabolism inhibition and promotion of protein synthesis (Layman 2003).

Oxidative stress is a condition in which the body produces too many free radicals, which are reactive oxygen species. These can damage DNA, cells and tissues. At the same time as their production increases, the body's antioxidant defense mechanisms also decrease. Many diseases have been linked to oxidative stress, including atherosclerosis (Batty et al 2022). Oxidative stress can be reduced through diet, where consumption of antioxidants is of great importance. Vitamins C and E are natural antioxidants.

Furthermore, recent studies showed that milk peptides are a source of antioxidant effects. One example is YFYPEL peptide, which is derived from bovine casein and is classified as an antioxidant compound. Chen et al. investigated how YFYPEL peptide can be used to reduce the incidence of the serious disease Necrotizing Enterocolitis, NEC. The intestinal mucosa becomes inflamed and dies, which often leads to infection. This disease mainly affects premature and sick children, and the exact reason why this happens is still unclear. The experiment was carried out on rats and the result was that the incidence of NEC was reduced, while intestinal cell migration was improved and intestinal inflammation was alleviated (Chen et al 2023).

3.1.2 Milk fat and MFGM

The consumption of saturated fatty acids has previously been linked to an increased risk of metabolic syndrome and cardiovascular disease in many studies during the last decades. Specifically, the saturated fatty acids lauric-, myristic- (14:0) and palmitic (16:0) acid have low-density lipoprotein (LDL)- and high-density lipoprotein- (HDL) cholesterol-increasing properties (Sand et al. 2006). Various lipoproteins transport lipids in the blood. In the form of Very Low-Density lipoprotein, F.A. and cholesterol are transported from the blood to adipose tissue. Parts of VLDL are then converted to Low density Protein LDL, which in turn transports the cholesterol produced in the liver to the body's cells. There, it is used to build cell membranes and as a component for steroid and bile salt synthesis. The remaining cholesterol is then transported with high density lipoprotein (HDL) out of the blood to be excreted by the liver. A high concentration of LDL is considered to increase the risk of cardiovascular disease because it can lead to the accumulation of fatty deposits in the arteries, making them stiff and narrower. On the other hand, HDL helps remove excess cholesterol from the arteries and thus prevents the accumulation of these fatty deposits (ibid).

Health effects of specific fatty acids have also been well studied. The short-chained butyric acid (4:0) constitutes approximately 10% of the total FA by weight. This fatty acid may be linked to cancer prevention and is a modulator of gene function (German 2007). In another study, caprylic acid (8:0) was shown to be potent bactericidal against coliform bacteria, while lauric acid (12:0) was most potent against enterococci (Sun et al. 2002).

Ruminant trans fatty acids (rTFA), which are different from industrial trans fatty acids, reduce blood pressure and insulin levels in the body. This was demonstrated in a study in which fasting blood samples were collected from 200 individuals in Canada. The fatty acid levels of 100 normal weight (BMI < 30 kg m^{-2}) and 100 overweight (BMI ≥ 30 kg m^{-2}) individuals were measured. Significantly lower blood pressure were observed in the individuals with higher levels of rTFA. The data suggested that rTFA may have positive effects on cardiometabolic health (Da Silva et al. 2015).

In one study, 31 experiments were observed that had been conducted on the relationship between regular-fat milk consumption and the risk of cardiometabolic disease risk factors (Taormina et al. 2024). In the majority of the studies, a relationship between cardiovascular disease and the intake of milk with a standaradized fat content (less than or equal to 3%) could not be established. However, one study showed that the risk of cardiovascular disease mortality was lower in individuals who consumed low-fat milk compared to individuals who consumed milk with 1.5% fat. In total, four studies evaluated the relationship between milk consumption and blood lipid proteins. There were conflicting results as to whether consumption resulted in a harmful or beneficial effect on blood lipid proteins. Finally, a positive correlation between a cardiorespiratory fitness score and milk intake could be measured in one study.

It is impossible to overlook the biological fat membrane that encloses fat drops (MFG) when looking at the properties of milk. MFGs are between 1-20 µm and mostly contain different types of TAGs. They are surrounded by Milk Fat Globule Membranes (MFGM) which consist of a phospholipid tri-layer surrounding proteins, lipids and cholesterol. Their main task is to envelope fat droplets to stabilize them in the aqueous environment of milk (Lopez 2011). Both humans and bovine milk naturally consists of these components. The structure and components of MFGM are believed to orginate from the apical plasma membrane of the secretory cells. The internal layer consists of phospholipids and proteins while the external layer consists of domains containing a large amount of cholesterol and sphingomyelin. Along the different layers of the membrane, there are glycolipids and proteins found. The proteins are linked to each other in a way that promote stabilization of the membrane (See figure 1).

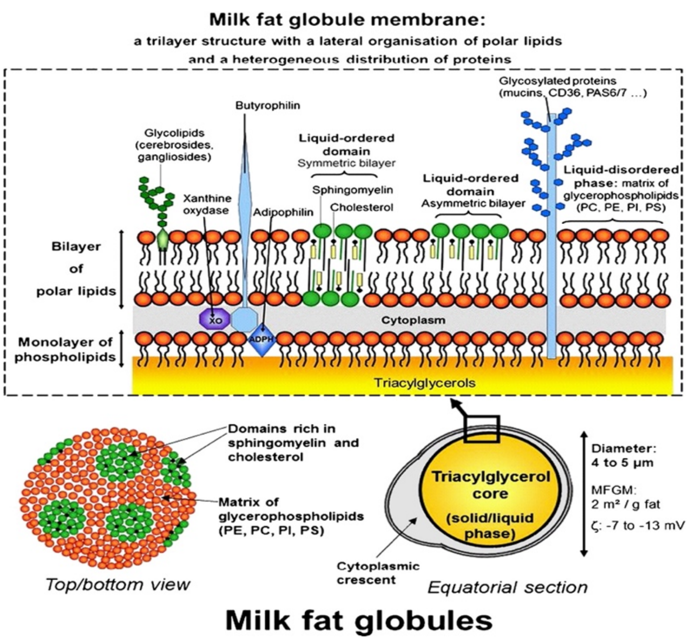

Figure 1. The structure of MFG and MFGM (Lopez 2011).

Several studies have shown that MFGM has a positive impact on health. For instance, Demmer et al. (2016) concluded that MFGM has properties that can attenuate the negative effects of dietary SFA. A cross-over study was conducted in which a high-fat meal consisting of palm oil (PO) was compared with a meal of PO together with a milk fraction rich in MFGM (PO+MFGM) consumed by overweight and obese men and women. Plasma glucose, insulin and lipid profiles were then measured. The results showed that consumption of PO+MFGM led to lower total cholesterol, LDL cholesterol and insulin (see figure 2).

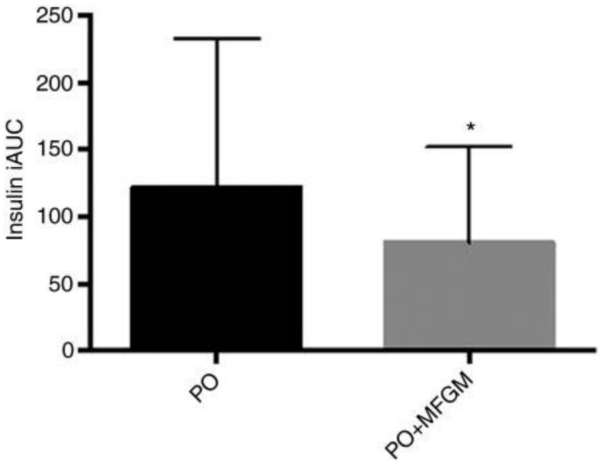

Figure 2. Insulin concentrations over the 6 hours fasting period after a meal containing PO and PM+MFGM (Demmer et al. 2016).

Zhao et al (2022) found that MFGM can promote the growth of so-called Bifidobacterium in the intestine. This gram-positive bacterium improves digestive health by promoting attachment and colonization in the GI tract. In another study, spatial memory and learning were measured in mice for 18 weeks after injection of MFGM. The results showed that the mice that had been exposed to MFGM had better cognition and spatial memory. This was achieved by successfully completing various tests. These findings were linked to the fact that MFGM reduces the loss of neural cells while promoting a more regular and even morphology of neural cells in the brain (Zhou et al. 2023).

3.1.3 Calcium

Calcium is an essential mineral. It is needed for the formation of teeth and bones, normal nerve function and blood clotting (Livsmedelsverket 2025b). Sufficient consumption prevents fractures, rickets and osteomalacia, which is a disease in which the bones become soft and weak. Calcium is found in foods in the form of water-soluble salts, with a few exceptions, and is found in most foods. However, it is not in high concentrations and has low bioavailability. Dairy products, along with leafy vegetables and nuts, are foods that contain large amounts of calcium. Concentrations in milk reach between 55-70% of the daily requirement and are considered one of the foods with the highest bioavailability. Calcium is absorbed mainly in the upper part of the ileum, which is the last part of the small intestine (Sanjuliàn 2025).

In a study by Kim et al. (2013), the association between calcium and biomarkers related to lipid metabolism and milk consumption in women with type 2 diabetes was investigated. A total of 509 women responded to a validated food-frequency questionnaire between 2005 and 2010. The results showed that individuals with a dairy product intake above the estimated average requirement for calcium revealed greater HDL-cholesterol than those with a calcium intake below the estimated average requirement (Kim et al. 2013). Simultaneously, another study found that milk-based calcium contributed to a reduction in LDL levels in the blood (Lorenzon et al. 2013). This is believed to be due to calcium's crucial role in lipid digestion. Calcium appears to inhibit lipase digestion by inducing flocculation, a process where small particles in a liquid or solution aggregate to form larger clumps, and increasing the surface area of lipase action (Mulet-Cabero & Wilde 2021).

3.2 Environmental Impact of Milk

During the last 30 years, the warmest periods on earth have been measured. At the same time, glaciers and ice sheets are melting, sea levels are rising, and greenhouse gas emissions are increasing in the atmosphere (IPCC 2014). It is mainly the emissions of methane and nitrous oxide from grazing cows as well as emissions from feed production that account for a large part of GHGE in the dairy sector. This is mainly by two ways; through methane emissions from the cow itself and through the resources required to produce their feed.

Although methane is about 80 times more potent a GHG than carbon dioxide, it has a shorter lifespan (Lynch et al 2020) (See Figure 3). It breaks down within 10 years. While it is not a long-term problem, the consequences are significant today (see figure 3).

The figure below shows the warming contribution over time if a one-off pulse emission of 1 million tonnes of carbon dioxide is emitted, compared to 1 million tonnes of carbon dioxide equivalent amount. This amount is defined as approximately. 0.036 million tonnes Methane or 0.0038 Nitrous oxide (Lynch et al. 2020).

Nitrous oxide is a natural gas produced by bacteria that convert nitrogen compounds in the soil. Compared to carbon dioxide, one kilogram of nitrous oxide has the same impact on the climate as almost 300 kilograms of carbon dioxide. Its lifespan is longer than methane, at around 110-115 years (see figure 3). Nitrous oxide emissions account for eight percent of total human GHG emissions, but there are no reliable methods of measuring actual emissions from agriculture today.

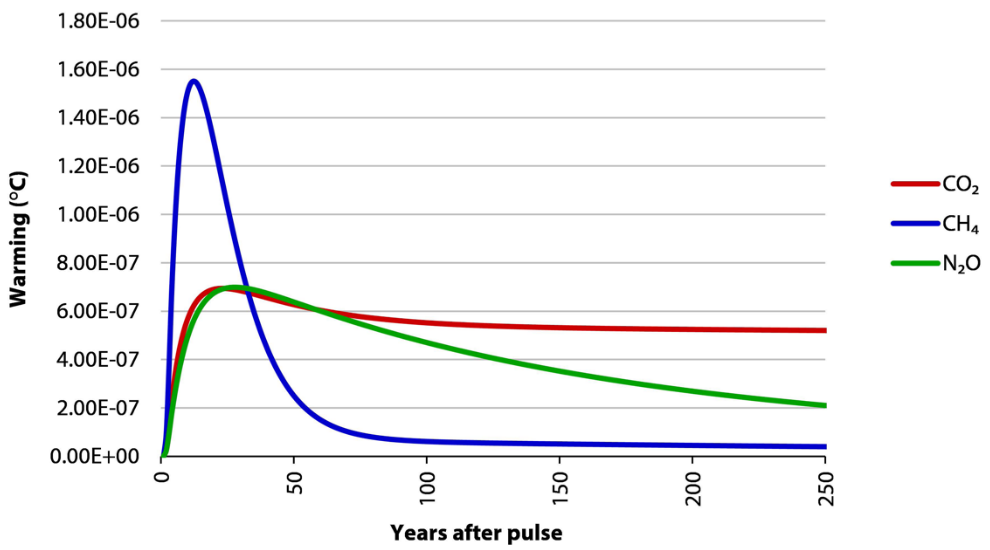

Figure 3. The three greenhouse gases presented in the figure are of different potency and have different degradation times. Methane degrades after 10-12 years but is much more potent than carbon dioxide, which however has a longer lifetime of about 1000 years (Lynch et al. 2020).

In Sweden, the number of dairy cows has decreased for many years. This trend is due, among other things, to the fact that milk yield per cow has increased and that agriculture in general has become more efficient (Swedish Board of Agriculture 2012). Milk yield, i.e. how much milk a cow produces, has a direct link to environmental impact. The more milk a cow produces, the more efficient the production is from a climate perspective. This is because the large emissions from the animal, such as methane and nitrous oxide, are distributed over a larger amount of milk. Statistics show that Denmark is the country with the highest milk yield, followed by Sweden, Finland, and Portugal (Jordbruksverket 2014).

The Swedish Board of Agriculture's report on *the impact of Swedish meat and milk production on biodiversity and climate* (2011) highlighted how important pasture-based milk production is for maintaining biodiversity. However, it has a greater climate impact than concentrate-based production. Milk production and biodiversity are greatly influenced by each other. In 2023, RISE developed a database to calculate biodiversity impacts on foods and ingredients. For semi-skimmed milk, a value of 8 fPDF/kg was shown for Swedish production and 21 fPDF/kg for Danish production (see figure 4). This means that more species are potentially lost in Denmark. In order to be able to make measurements of biodiversity, fPDF is used, which stands for *Potentially Disappeared Fraction*. This measurement describes the potential species loss caused by human land use. The results are presented in femto-PDF because PDF per kilogram of a food is low, often raised to minus 15 (RISE 2023).

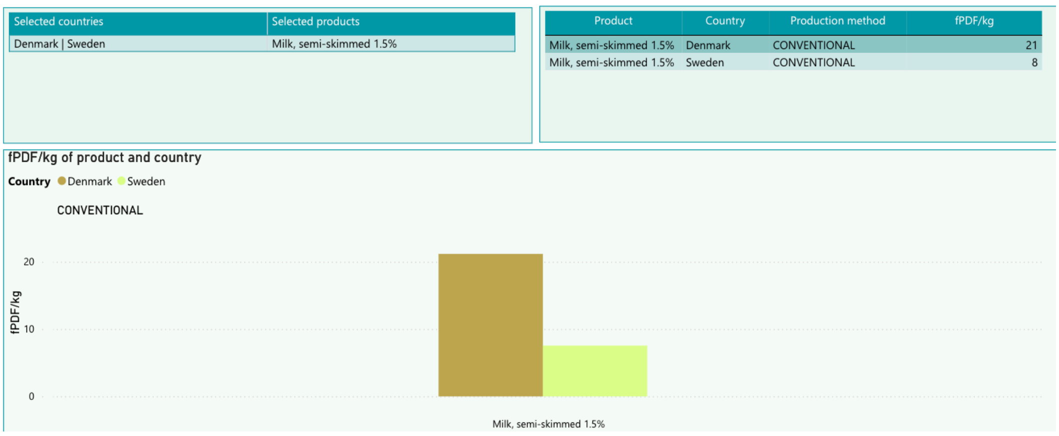

Figure 4. fPDF calculation of semi-skimmed milk products in Sweden and Denmark (RISE 2023).

Carbon sequestration refers to the transfer of carbon from the atmosphere through plants to the soil, where it is stored and contributes to a global increase in soil carbon stocks (Don et al. 2023). A report from the Swedish University of Agricutural Sciences examined how the carbon stock had changed in Swedish agricultural land over 10 years. The results showed that the increase in carbon stock was greatest on dairy farms, a positive climate effect of 1.4 tons of carbon dioxide per hectare and year. Calculations that were made showed a reduction of approximately 0.22 kg of carbon dioxide per kg of milk. A connection between the amount of pasture on the farm and the carbon content of the soil was found (Henryson et al. 2022).

3.3 Relationship between Dairy Matrix and Environmental Impact

Despite the high content of saturated fatty acids in milk, there is no correlation between consumption and CVD. However, there is evidence that replacing full-fat milk with low-fat milk can contribute to overall better cardiovascular health (Holven & Sonestedt 2024).

Milk is considered to have a high Nutrient Rich Food Index. It is a type of scoring system that ranks foods based on their nutritional content. A high value indicates that the food contains many essential nutrients but few calories. A link between individuals consuming NRF such as milk and lower energy intake (kcal) (Streppel et al. 2012).

At the same time, milk has a higher impact on the climate than many other foods. Sorley et al. (2024) investigated which factors influenced the carbon footprint in Western Europe. The results showed that emissions from enteric fermentation constituted the largest share of the total emissions. In another study, a systematic review and meta-analysis was conducted on, among other things, the carbon footprint of milk. This was measured as global warming potential in CO2e per kg product. For Western Europe, the value was approximately 1.7 CO2e per kg milk and worldwide approximately 2.8 CO2e per kg milk (Gerber et al 2013).

Unlike studies that examine the nutrient density of milk in relation to climate impact, there do not seem to be exact figures or methods for calculating the dairy matrix in relation to climate impact. In this case, reasoning has instead been more important.

Theoretically, Peters (n.d) meantioned that it is possible to reduce carbon dioxide emissions if you stop consuming milk. However, it is important to point out that you would then miss out on the nutrients that this food provides and must be compensated by eating more of other things, such as plant-based products. They also have a climate footprint. A dairy-free diet produces approximately 3.53 kg of carbon dioxide emissions, while a diet that includes dairy products produces 3.67 kg of carbon dioxide emissions (Peters n.d.).

Smith et al. (2022) used the relatively new DELTA Model, which calculates the nutrient supply from global food production. The results showed that milk contributes to the global supply of 28 nutrients out of a total of 29 considered (see Table 1). Furthermore, the bioavailability of the nine essential amino acids was examined (See table 2).

Table 1. A summary of milk production to global nutrient availability, year 2018 (smith et al. 2022). Not all nutrients from the study are included in this table.

Nutrient	**Percentage of global availability provided by milk nutrition**	**Ranked nutrient contribution of milk nutrition**
Carbohydrates	3	5th
Energy	7	3rd
Fat	15	1st
Fiber	0	No contribution
Protein	12	3rd
Calcium	49	1st
Vitamin B2	24	1st
Magnesium	9	4th
Zinc	8	3rd

Table 2. Bioavailability coefficients used for protein and indispenseable amino acids in the DELTA Model for milk (Smith et al. 2022).

Nutrient	Bioavailability
Protein	0.95
Tryptopphan	0.98
Threonine	0.97
Leucine	1
Lysine	0.98
Methionine	0.92
Cystine	0.94
Histidine	1

4. Discussion

In this section, the results from the literature are summarized and synthesized. The discussion highlights the strong evidence for milk's health effects from a Dairy-Matrix perspective, discusses the potential benefits of milk production and identifies any potential knowledge gaps found.

4.1 Synthesis of Findings

Several studies have shown a link between saturated fatty acids and metabolic syndrome and cardiovascular disease. However, it could not be proven that milk consumption would have a direct link to these diseases. Current research highlights the importance of the Dairy Matrix, where the substances and composition of milk form structures that are of great importance for human health.

The membrane surrounding the lipid droplets, MFGM, plays an important role in the regulation of insulin, nerve cell health and digestive tact. MFGM contains, in addition to lipids, also proteins. There is strong evidence that proteins, specifically when hydrolyzed to peptides, can have positive effects on health. GMP has antioxidant and anti-inflammatory properties (Còrdova-Dàvalas et al 2019). The YFYPEL peptide has also been studied previously. The casein-derived peptide prevented oxidative damage in Caco-2 cells, a human cell line used in pharmaceutical research that mimics intestinal enterocytes (Chen et al. 2023). Qian et al. (2016) also reported that YFYPEL has strong sleep-enhancing effects.

Milk and dairy production has a negative impact on the environment by being a contributing factor to GHGE. Intensifying farming by, among other things, increasing milk production per cow has, however, been shown in previous studies to have a reduced environmental impact (Bava et al 2014). In addition, it is important to take into account the stored organic carbon and how much impact it has on the climate footprint of dairy products (Henryson et al. 2022). Research from the Swedish Board of Agriculture (2011) has confirmed that pasture cultivation can increase the carbon content of arable land. On the other hand, cereal cultivation seems to have the opposite effect.

The reduction in biodiversity caused by milk production is relatively low compared to other foods. In the RISE biodiversity database, conventionally produced skim milk from Sweden and Denmark was compared with conventionally produced soy drink from Greece, among others (see Figure 5). The results show that soy drink has a significantly higher negative impact on biodiversity compared to milk. As Dr. Peters mentioned, excluding milk from the diet does not always mean that we reduce our environmental or climate footprint. On the contrary, we need to replace milk with other products, which may not have the same bioavailability as milk (Smith et al. 2022).

Product	Country	Production method	fPDF/kg
Milk, semi-skimmed 1.5%	Denmark	CONVENTIONAL	21
Soy milk	Greece	CONVENTIONAL	78
Milk, semi-skimmed 1.5%	Sweden	CONVENTIONAL	8

Figure 5. Comparison of soydrink and milk (1.5%) and their fPDF/kg (RISE 2023).

However, it is important to consider the limitations of the RISE Database. Feed consumed by grazing animals is not only grown on the farm but is sometimes imported from other parts of the world. In addition, there are other farm inputs that need to be included in the calculations, such as electricity generation and extraction of mineral fertilizers. These inputs also have a direct impact on biodiversity and must be included in biodiversity footprint calculations, which can be very complex (RISE 2023).

4.2 Knowledge Gaps

As the studies suggest, a balance can be achieved between the health effects of milk as a matrix and consideration of the environmental and climate footprint. However, it has been difficult to weigh them together. The problem seems to lie primarily in how to compare these two quantitatively. The updated nutritional recommendations from 2023 continue to recommend moderate intake of low-fat milk and milk products. A more nuanced view of milk as a whole, both from a health and environmental perspective, has been included this time (NNR 2023). However, this report does not describe any quantitative findings.

5. Conclusion

The conclusion is presented by briefly summarizing the most important findings and presenting the current knowledge gaps. Finally, the research question is answered and recommendations are given for future research.

5.1 Research Question

It has been difficult to find studies that answer the question of this report due to a lack of data and comparisons between the concepts of health and environment. The studies that have been reviewed have addressed one of the two topics and an attempt has been made to interweave these with each other. A balance between environmental considerations and health benefits in milk consumption can be achieved by emphasizing the positive environmental aspects of milk production. For instance, pasture cultivation can enhance the carbon content of arable land, and increasing the production of Swedish milk, which has a comparatively low negative impact on biodiversity, can contribute positively to environmental outcomes. Simultaneously, it is essential to consider the overall composition of milk rather than focusing solely on individual nutrients.

As previously mentioned, it is difficult to make measurments on the Dairy matrix and the environmental impact of milk. It is known that milk is a food that has many good properties from a health perspective and there are recommendations for intake. But is it worth continuing to produce and consume this product given the mentioned environmental impact that it has? The literature study points to the fact that it is possible to balance milk consumption from a health perspective and a concern for the environment.

5.2 Recommendations for Future Research

Further research in this area is highly relevant, as there is currently a lack of quantitative data linking health and environmental factors of milk. Establishing concrete metrics and calculations will enable more robust analysis and meaningful comparisons, moving the discourse beyond theoretical reasoning. A particular interest for the future is to further explore the whole structure of milk and its health effects over longer periods and at the same time be able to compare this to the environmental consequences of production and consumption. A more holistic sustainability assessment is of great relevance where where the focus is on all aspects of sustainability.

References

Batty, M., Bennett, M., Yu, E (2022). The Role of Oxidative Stress in Atherosclerosis. Cells, 11(23), pp. 3843 https://doi.org/10.3390/cells11233843

Bava, L., Sandrucci, A., Zucali, M., Guerci, M., Tamburini, A (2014). How can farming intensification affect the environmental impact of milk production? Journal of Dairy Science, 97(7), pp. 4579-4593 https://doi.org/10.3168/jds.2013-7530

Bell, E., Bryman, A., and Harley B. (2019) Business Research Methods. 5 ed. Oxford: OUP.

Blomhoff, R., Andersen, R., Arnesen, E.K., Christensen, J.J., Eneroth, H., Erkkola, M., Gudanaviciene, I., Halldorsson, T.I., Høyer-Lund, A., Lemming, E.W., Meltzer, H.M., Pitsi, T., Schwab, U., Siksna, I., Thorsdottir, I., Trolle, E. (2023). Nordic Nutrition Recommendations 2023. Copenhagen: Nordic Council of Ministers, 2023

Chen, W., Chen, Y., Qian, Y., Zhang, J., Hu, X., Yan, X., Jiang, C., Yao, S., Yu, Q., Chen, X., Han, S (2023). The casein-derived peptide YFYPEL alleviates intestinal epithelial cell dysfunction associated with NEC by regulating the PI3K/AKT signaling pathway. Food & Function, 14:8, pp 3769-3778 https://doi.org/10.1039/D2FO02400D

Córdova-Dávalos, L. E., Jiménez, M., & Salinas, E. (2019). Glycomacropeptide Bioactivity and Health: A Review Highlighting Action Mechanisms and Signaling Pathways. Nutrients, 11(3), 598. https://doi.org/10.3390/nu11030598

Cynthia Q Sun, Charmian J O'Connor, Anthony M Roberton,

The antimicrobial properties of milkfat after partial hydrolysis by calf pregastric lipase, Chemico-Biological Interactions, 140(2), pp 185-198 https://doi.org/10.1016/S0009-2797(02)00016-9

Da Silva, M.S., Julien, P., Pérusse, L. et al. Natural Rumen-Derived trans Fatty Acids Are Associated with Metabolic Markers of Cardiac Health. Lipids 50, pp. 873–882 https://doi.org/10.1007/s11745-015-4055-3

Demmer, E., Van Loan, M. D., Rivera, N., Rogers, T. S., Gertz, E. R., German, J. B., Smilowitz, J. T., & Zivkovic, A. M. (2016). Addition of a dairy fraction rich in milk fat globule membrane to a high-saturated fat meal reduces the postprandial insulinaemic and inflammatory response in overweight and obese adults. Journal of nutritional science, 5, e14. https://doi.org/10.1017/jns.2015.42

Don, A., Seidel, F., Leifeld, J., Kätterer, T., Martin, M., Pellerin, S., Emde, D., Seitz, D., Chenu, C (2023). Carbon sequestration in soils and climate change mitigation – Definitions and pitfalls. Global Change Biology, 30(1) https://doi.org/10.1111/gcb.16983

Europeiska rådet (2025). Parisavtalet om klimatförändringar. https://www.consilium.europa.eu/sv/policies/paris-agreement-climate/

FAO (2025). Milk composition. Gateaway to dairy production and products. https://www.fao.org/dairy-production-products/products/milk-composition/en [2025-03-10]

German, J.B (2007). Butyric acid: A role in cancer prevention. Nutrition Bulletin, 24(4), pp. 203-209 https://doi.org/10.1111/j.1467-3010.1999.tb00910.x

Guo, Y., Jiang, X., Xiong, B., Zhang, T., Zeng, X., Wu, Z., Sun, Y., Pan, D (2019). Production and transepithelial transportation of angiotensin-I-converting enzyme (ACE)-inhibitory peptides from whey protein hydrolyzed by immobilized Lactobacillus helveticus proteinase. Journal of Dairy Science, 102(2) pp. 961-975 https://doi.org/10.3168/jds.2018-14899

Haug, A., Høstmark, A.T. & Harstad, O.M. Bovine milk in human nutrition – a review. Lipids Health Dis 6, 25 (2007). https://doi.org/10.1186/1476-511X-6-25

Henryson, K., Meurer, K. H. E., Bolinder, M. A., Kätterer, T., & Tidåker, P. (2022). Higher carbon sequestration on Swedish dairy farms compared with other farm types as revealed by national soil inventories. Carbon Management, 13(1), pp 266–278 https://doi.org/10.1080/17583004.2022.2074315

Holven, K.B & Sonestedt, E (2024). Milk and dairy products – A scoping review for -nordic Nutrition Recommendations 2023. Food & Nutrition Research, 68, pp. 10486 https://doi.org/10.29219/fnr.v68.10486

IPCC (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups 1, 2 and 3 to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. 151.

Jelen, P. (2022). Lactose: Occurrence, properties, reactions, and significance. Advanced *Dairy Chemistry – 3 Lactose, Water, Salts and Minor Constituents.* 4th edition., Springer Nature Switzerland AG. 1-16

Jordbruksverket (2012). Marknadsöversikt – Mjölk och mejeriprodukter. https://www2.jordbruksverket.se/webdav/files/SJV/trycksaker/Pdf_rapporter/ra12_7.pdf [2025-05-02]

Jordbruksverket (2014). Jordbruksstatistik årsbok 2013. https://jordbruksverket.se/download/18.5b7c91b9172c01731757f9d4/1592481512562/2013.pdf [2025-04-10]

Kim, J., Hwang, J, Kim, K.N., Choi, Y., Chang, N., Huh, K (2013). Relationship between Milk and Calcium intake and Lipid Metabolism in Female Patients with Type 2 Diabetes. Yonsei Medical Journal, 54(3), pp. 626-636 https://doi.org/10.3349/ymj.2013.54.3.626

Layman, D.K (2003). The Roleof Leucine in Weight Loss Diets and Glucose Homoestatis 1,2. The Journal of Nutrition, 133(1), pp. 2615-2675 https://doi.org/10.1093/jn/133.1.261S

Lin, T., Meletharayil, G., Kapoor, R., & Abbaspourrad, A. (2021). Bioactives in bovine milk: chemistry, technology, and applications. Nutrition reviews, 79(2), pp. 48–69. https://doi.org/10.1093/nutrit/nuab099

Livsmedelsverket. (2023). Livsmedelsverkets livsmedelsdatabas version 2023-06-13. Sök näringsinnehåll - Livsmedelsverket. [2025-05-12]

Livsmedelsverket (2025a). Mejeriprodukter. https://www.livsmedelsverket.se/matvanor-halsa--miljo/kostrad/kostrad-vuxna/mejeriprodukter [2025-05-12]

Livsmedelsverket (2025b). Salt och mineraler – Kalcium. https://www.livsmedelsverket.se/livsmedel-och-innehall/naringsamne/salt-och-mineraler1/kalcium [2025-06-09]

Lopez, C. (2011). Milk fat globules enveloped by their biological membrane: Unique colloidal assemblies with a specific composition and structure. *Current Opinion in Colloidal & Interface Science*. 16(5), pp. 391-404. https://doi.org/10.1016/j.cocis.2011.05.007

Lorenzen, J.K., Jensen, S.K., Astrup, A. (2013). Milk minerals modify the effect of fat intake on serum lipid profile: results from an animal and a human short-term study. Cambridge University Press. 111(8), 1412-1420. https://doi.org/10.1017/S0007114513003826

Lynch, J., Garnett, T., Persson, M., Röös, E. & Reisinger, A. (2020). Methane and the sustainability of ruminant livestock (Foodsource: building blocks). Food Climate Research Network, University of Oxford. https://tabledebates.org/sites/default/files/2021-09/FCRN%20Building%20Block%20-%20Methane%20and%20the%20sustainability%20of%20ruminant%20livestock.pdf

Mulet-Cabero, A. I., & Wilde, P. J. (2021). Role of calcium on lipid digestion and serum lipids: a review. Critical Reviews in Food Science and Nutrition, 63(6), pp. 813–826. https://doi.org/10.1080/10408398.2021.1954873

Mulet-Cabero, A. I., Torres-Gonzalez, M., Geurts, J., Rosales, A., Farhang, B., Marmonier, C., Ulleberg, E. K., Hocking, E., Neiderer, I., Gandolfi, I., Anderson, L., Brader, L., Vermaak, M., Cameron, M., Myrup Christensen, M., Haryono, R., & Peters, S. (2024). The Dairy Matrix: Its Importance, Definition, and Current Application in the Context of Nutrition and Health. Nutrients, 16(17), pp 2908. https://doi.org/10.3390/nu16172908

Månsson H. L. (2008). Fatty acids in bovine milk fat. Food & nutrition research, 52 https://doi.org/10.3402/fnr.v52i0.1821

Peters, S (n.d). Balancing sustainable diets with environmental impacts to promote healthier lives. https://fil-idf.org/news_insights/balancing-sustainable-diets-with-environmental-impacts-to-promote-healthier-lives/ [2025-04-11]

RISE (2023). Biodiversitetsdatabas för livsmedel. https://www.ri.se/sv/expertisomraden/expertiser/biodiversitetsdatabas

Sand, O., Sjaastad, Q.V., Haug, E., Bjålie, J.G. (2006). *Människokroppen Fysiologi och anatomi.* 2nd edition., Liber AB

Sanjulian, L., Fernàndez-Rico, S., Gonzàlez-Rodriguez, N., Cepeda,, A., Miranda, J.M., Fente, C., Lamas, A., Regal, P (2025). Nutrients, 17(4), pp. 646 https://doi.org/10.3390/nu17040646

Sorley, M., Casey, I., Styles, D., Merino, P., Trindade, H., Mulholland, M., Zafra, C.R., Keatinge, R., Le Gall, A., O'Brien, D., Humphreys, J (2024). Factors influencing the carbon footprint of milk production on dairy farms with different feeding strategies in western Europ. Journal of Cleaner Production, 435 pp. 140104 https://doi.org/10.1016/j.jclepro.2023.140104

Sun, C.Q., O'Connor, C.J., Roberton, A.M (2002). The antimicrobial properties of milkfat after partial hydrolysis by calf bregastric lipase. Chem Biol Interac, 140(2) doi: 10.1016/s0009-2797(02)00016-9

Taormina, V.M., Unger, A.L., Kraft, J (2024). Full-fat dairy products and cardiometabolic health outcomes: Does the dairy-fat matrix matter? Frontiers Nutrition and Metabolism, 11 https://doi.org/10.3389/fnut.2024.1386257

United Nations Environment Programme (2023). Frontiers 2023, What's Cooking? An assessment of the potential impacts of selected novel alternatives to conventional animal products. https://doi.org/10.59117/20.500.11822/44236

World Wildlife Fund (2019). Milk's impact on the environment. Issue: Winter 2019. https://www.worldwildlife.org/magazine/issues/winter-2019/articles/milk-s-impact-on-the-environment [2025-03-15]

Zhou, Y., Zou, X., Feng, R., Zhan, X., Hong, H., Luo, Y., Tan, Y (2023). Improvement of Spatial Memory and Cognitive Function in Mice via the Intervention of Milk Fat Globule Membrane. Nutrients. 15(3), pp 534 https://doi.org/10.3390/nu15030534

Zhao, J., Yi, W., Liu, B., Dai, Y., Jiang, T., Chen, S., Wang, J., Feng, B., Qiao, W., Liu, Y., Zhou, H., He, J., Hou, J., Chen, L (2021). MFGM components promote gut Bifidobacterium growth in infant and in vitro. European Journal of Nutrition, 61, pp 277-288 https://doi.org/10.1007/s00394-021-02638-5

Willet, W., Rockström, J., Loken, B., Springmann, M., Lang, P., Vermeulen, S (2019). Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. The Lancet commissions, 393:10170 pp. 447-492. https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(18)31788-4/fulltext

Popular science summary

Cow's milk and other dairy products are a common food consumed all over the world. It has long been and still is an important source of nutrition and, in addition to water, also contains carbohydrates, fat, proteins, minerals and a variety of vitamins. These substances are all important for covering our nutritional needs and maintaining good health. However, it is also important to mention that milk is rich in saturated fatty acids, which have previously been linked to negative health effects. It is precisely because of this that authorities recommend the intake of low-fat milk for adults. At the same time, there is an ongoing debate about how environmentally sustainable it is to continue producing cow's milk, given the negative effects that production has on, for example, increased global temperatures. There are currently no clear calculations or methods to compare the health effects of milk with its environmental impact and thus be able to answer the question of whether a balance between health and the environment can be achieved when consuming cow's milk. Therefore, it is interesting to take a closer look at the ongoing research and in some way try to connect these.

Currently, a relatively new concept of the health effects of cow's milk has emerged, namely the dairy matrix. It aims to describe the composite structure and interactions of milk and dairy products beyond the individual nutrients. Research today shows that there are many other components that have health benefits such as bioactive peptides and fat-enclosing membranes. These have been shown to be able to inhibit oxidative stress, regulate blood sugar levels, etc.

Dairy production is a contributing factor to greenhouse gas emissions such as methane and nitrous oxide, two powerful gases that contribute to global warming and have devastating consequences for our planet. However, methane is a short-lived gas that stays in the atmosphere for decades, rather than carbon dioxide which has a much longer lifespan. Milk production can also be linked to certain environmental benefits. These findings have emerged primarily within Swedish production. Increased carbon sequestration, little negative impact on biodiversity and an efficient milk yield that streamlines production and thereby reduces greenhouse gas emissions are some examples of the positive environmental effects.

It is difficult to make a nuanced assessment and comparison between the two aspects of health and environment in connection with milk consumption, even though research shows that it is possible to balance these two. More studies and experiments need to be carried out to be able to provide a clearer context.

However, the recommendations that exist in the Nordic countries today include both health and environmental sustainability, where it is still recommended to consume low-fat milk.

In conclusion, there is a promising future for the production and consumption of cow's milk where positive health effects and environmental sustainability can be met and a balance can be achieved. This is done by including the dairy matrix concept and highlighting the positive environmental effects of Swedish milk production.

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