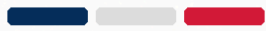


FLSDiet®

FRENCH LOW SULFUR DIET



Practical guide

HEALTHCARE PROFESSIONALS

Standard and vegetarian — The course of the diet and food reintroduction

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With menus and recipes by Clara Materne, Nutritional Therapist

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HEALTHCARE PROFESSIONAL GUIDE

The course of the diet / Reintroduction steps / Supportive approaches to problems associated with sulfur-containing compounds

Practical guide for healthcare professionals, common to Standard and Vegetarian FLSDiet®

The French Low Sulfur Diet (FLSDiet®) combines detailed information about a diet low in sulfur-containing compounds with a selection of enjoyable recipes carefully adapted to its principles. It was designed to reconcile nutritional requirements, the pleasure of eating and culinary creativity, with the distinctive gastronomic “French Touch”. It was first presented at the second Microbiome360 congress, organised by D-CODE LAB in Lyon, France, on 3 and 4 October 2026. Created by Dr Christian Boyer (PhD) and Dr Amin Gasmi (PhD). Menus and recipes by Clara Materne, nutritional therapist.

Important information

FLSDiet® (French Low Sulfur Diet) is a temporary dietary approach intended to support the management of certain digestive sensitivities or reactions associated with sulfur-containing compounds. This document is provided for educational and informational purposes. It does not constitute a diagnosis, medical prescription or treatment, and does not replace consultation with a doctor or qualified healthcare professional. The professional FLSDiet® guide is intended exclusively for healthcare professionals and has an educational and informational purpose based on scientific data.

THE FLSDIET® KIT

FLSDiet® is available as a complete kit addressing issues associated with sulfur-containing compounds. It includes:

- Two lists of foods to favour, limit or avoid: one for the standard diet and one for the vegetarian diet;
- Two practical guides, one for patients and one for healthcare professionals, explaining the instructions and the elimination and reintroduction phases. Both guides apply to the standard and vegetarian versions of FLSDiet®.
- A recipe booklet, also shared by the standard and vegetarian versions of FLSDiet®.

INTRODUCING FLSDIET®

FLSDiet® (French Low Sulfur Diet) is a supportive diet specifically designed for conditions involving an overgrowth of hydrogen sulfide (H₂S)-producing bacteria, also referred to as ISO (Intestinal Sulfide Overproduction). ISO may involve H₂S-producing bacterial overgrowth in the large intestine (LIBO H₂S, Large Intestinal Bacterial Overgrowth) and/or in the small intestine (SIBO H₂S, Small Intestinal Bacterial Overgrowth).

FLSDiet® involves temporarily adopting an eating pattern with two complementary aims:

- reduce microbial, and also endogenous, production of hydrogen sulfide (H₂S);
- To limit the overgrowth of intestinal bacteria that produce H₂S.

To achieve these aims, FLSDiet® limits, in particular:

- animal products rich in sulfur-containing amino acids (cysteine and methionine) and taurine, or all animal products in Vegetarian FLSDiet®;
- starchy foods (cereals, pseudocereals and similar products), nuts and seeds rich in sulfur-containing amino acids or potentially less well tolerated;
- Saturated fats.
- Sulfur-containing compounds in plant foods, particularly the organosulfur compounds found in the Brassicaceae and Alliaceae families.
- Sulfites and sulfates.
- More generally, any foods, ingredients, dietary supplements or additives that may increase intestinal H₂S production or encourage the growth of bacteria that produce it.

FLSDiet® may also be considered for people with intolerance to sulfur-containing compounds. Its vegetarian version is particularly suited to this situation and to people with severe ISO (Intestinal Sulfide Overproduction), particularly when accompanied by multiple, intense and/or systemic symptoms.

“Intolerance to sulfur-containing compounds” does not mean an allergy to sulfur. It describes an imbalance between the amounts of sulfur-containing compounds supplied by food or produced by the body and its microbiota, and the body’s capacity to metabolise and eliminate them.

Vegetarian FLSDiet® is primarily intended for people who tolerate at least small amounts of pulses. When pulses are poorly tolerated, particular care is needed to ensure sufficient protein intake. Powdered pea or rice protein preparations may be considered according to individual tolerance. Another option is Standard FLSDiet®, which allows chicken and fish.

Because it restricts animal products and sulfur-containing amino acids more substantially, the strict phase of the vegetarian version is not intended to be prolonged. It is essential to maintain a protein intake of at least 1 g/kg of body weight per day, adjusted to individual needs. Additive-free BCAAs

(leucine, isoleucine and valine) may be considered to supplement amino acids involved in muscle anabolism, but must not replace sufficient complete protein. Dietetic support is recommended to prevent nutritional imbalances and deficiencies.

French Low Sulfur Diet has two phases:

- Phase 1 — Strict elimination: a maximum of 2 to 3 weeks for the standard version and a maximum of 2 weeks for the vegetarian version. Symptoms may sometimes improve rapidly, within the first week.
- Phase 2 — Food reintroduction: gradual, individualised reintroduction, which may extend over 2 to 3 months when full reintroduction is planned.

The aim is to gradually reintroduce as wide a variety of foods as possible, according to individual tolerance, while avoiding unnecessarily prolonged restrictions. It is essential to remind patients that the elimination phase of Vegetarian FLSDiet® must never exceed two weeks.

THE TWO PHASES OF FLSDiet®

PHASE 1 — Elimination phase of Standard and Vegetarian FLSDiet®

Duration: 2–3 weeks for the standard version; a maximum of 2 weeks for the vegetarian version.

Food tables can be found in the FOOD LIST for FLSDiet® and Vegetarian FLSDiet®.

During this first phase, remove all foods listed under “Avoid or reintroduce later”.

The permitted foods are those listed under:

- “Foods to favour”;
- “Foods to moderate and requiring particular care”.

Where maximum amounts per meal or per day are specified, they must be respected.

Foods in the “Limit and monitor tolerance carefully” category tend to trigger more reactions in some patients, for reasons that may or may not be directly related to ISO. This classification is not a recommendation to eliminate these foods routinely. Instead, intake should be adjusted to individual tolerance.

ISO (Intestinal Sulfide Overproduction) may be accompanied by symptoms suggestive of histamine intolerance. At physiological concentrations, H₂S may stabilise mast cells, whereas excessive production could promote inflammation of the intestinal mucosa and increase mast cell activation and histamine release.

Some intestinal bacteria, particularly within the phylum Pseudomonadota (formerly Proteobacteria), can produce both hydrogen sulfide (H₂S) and histamine. This dual metabolic potential, found in some species of Klebsiella, Escherichia, Proteus and Fusobacterium and in Clostridium perfringens, could increase the intestinal histamine load in dysbiosis associated with excessive H₂S production.

FLSDiet® therefore includes moderation of foods rich in histamine and other amines, foods that may promote histamine release, and foods that may inhibit DAO (the enzyme that breaks down histamine), without imposing severe restrictions.

In cases of marked histamine intolerance, it may be preferable to start with a diet specifically adapted to this problem for a few weeks before beginning FLSDiet®.

Freshness and storage conditions are essential in relation to histamine, particularly for meat and fish. Their histamine content can rise rapidly if the cold chain is interrupted or storage is prolonged. Choose exceptionally fresh products and, where possible, fish frozen at sea directly on board fishing

vessels, to limit histamine formation. Fruit and vegetables should also be fresh, preferably without blemishes or signs of deterioration, and should not be allowed to become overripe.

Effects of cooking on taurine and plant-derived sulfur-containing compounds

Boiling Brassicaceae vegetables in plenty of water reduces certain water-soluble sulfur-containing compounds, particularly glucosinolates. For highly sensitive people, cooking in two successive waters may substantially limit intolerance reactions. Poaching meat and/or fish in stock also removes some taurine, which is highly water-soluble.

Support for intolerance to sulfur-containing compounds and reduction of systemic symptoms associated with hydrogen sulfide (H₂S)

The “sulfur bucket” model offers a simple illustration of accumulation. The bucket fills with sulfur-containing compounds supplied by food, produced by the body and generated by the intestinal microbiota, particularly H₂S. It empties through processing, oxidation and elimination. When metabolic capacity is sufficient, sulfur-containing compounds are generally well tolerated. When the overall sulfur load exceeds metabolic and elimination capacity, the bucket “overflows”: reactive metabolites such as H₂S or sulfites may accumulate and cause various symptoms.

The transsulfuration pathway is central to endogenous sulfur metabolism and contributes downstream to sulfate production, a stable and largely unreactive terminal form. Dysregulation of this pathway or subsequent metabolic steps may promote excess H₂S or sulfite production and/or insufficient sulfate production. The intestinal microbiota may also generate excessive H₂S which, when local detoxification capacity is exceeded, can enter the systemic circulation and cause symptoms outside the digestive system in addition to common digestive symptoms.

Four approaches may be considered to improve tolerance to sulfur-containing compounds, support sulfate availability and limit symptoms associated with excess H₂S:

- Epsom salt (magnesium sulfate) foot or body baths may be considered as an approach intended to supply sulfate through the skin, without passing directly through the digestive tract and therefore without directly providing substrates to intestinal H₂S-producing bacteria. It is advisable to start with foot baths and increase the amount gradually.
- Molybdenum is an essential cofactor for sulfite oxidase (SUOX), the enzyme that converts sulfites into sulfates. Experimental data suggest that molybdenum may also help reduce H₂S production by sulfate-reducing bacteria (SRB).
- Coenzyme Q10 is required for the proper function of SQOR, a mitochondrial enzyme involved in the first step of H₂S oxidation and detoxification.
- Hydroxocobalamin, a form of vitamin B12, may help trap H₂S by binding to it. It can also bind thiosulfate, an intermediate in H₂S detoxification, for which it may have even greater affinity. It thus helps reduce H₂S and limit systemic symptoms.

These four approaches may be considered from phase 1 of FLSDiet® and continued during phase 2 for as long as deemed necessary.

PHASE 2 — Reintroduction phase of Standard and Vegetarian FLSDiet®

Duration: 2–3 months for full reintroduction using option 1

Gradual reintroduction by food group

Previously excluded foods should be reintroduced gradually by food group (11 groups), in the order shown below. Test each group separately and reintroduce the listed foods one at a time, starting with small amounts.

Groups containing foods not normally eaten may be skipped to move directly to the next group. The alcohol group is entirely optional: it does not need to be tested to continue food reintroduction.

If a group is poorly tolerated, do not stop the whole process. Continue with the following groups in the planned order. Poorly tolerated groups may be tested again once the others have been reintroduced. Foods that are well tolerated during testing may be retained in the diet, at amounts and frequencies for which good tolerance has been confirmed.

Finally, foods normally eaten before the diet but not included in the 11 groups below may be reintroduced gradually only after reintroduction of the FLSDiet® groups has been completed or attempted.

Reintroduction order: groups and foods

Broccoli → cauliflower → (red meat: veal) → artichoke → (fish) → eggs → asparagus → dairy: aged cheese, then yoghurt and cream → cooked leeks and onions → cooked garlic → (seafood: prawns) → (wheat), then oats → buckwheat and quinoa → (alcohol) → other foods

Blue text and parentheses indicate optional reintroduction, either in all cases (e.g. alcohol) or depending on the diet followed (e.g. meat, fish and seafood in the vegetarian version).

Vegetarian FLSDiet® may also be followed by omnivores who need to restrict animal products further. The reintroduction phase therefore includes meat and fish by default. For vegetarians, reintroduction remains optional, although it may be considered for potential benefits, particularly for fish. To maintain a vegetarian diet, reintroduction may be limited to animal products compatible with dietary habits, such as eggs and dairy.

Group 1 — Brassicaceae vegetables

Start by gradually reintroducing broccoli, then cauliflower. Initially, cook these vegetables thoroughly in plenty of boiling water. If well tolerated, shorter cooking times or steaming may be tested later. Other Brassicaceae vegetables (cabbage, red cabbage, Brussels sprouts, etc.) may be reintroduced later.

(Group 2 — Red meat)

Initially reintroduce only small amounts of lean veal, without sauce or cream. Once tolerance to veal is confirmed, other meats, particularly beef and duck, may be tested gradually. Pork should be reintroduced much later. Freshness and quality are essential.

Group 3 — Artichokes

Artichokes may first be reintroduced as thoroughly rinsed canned artichoke hearts, followed by small amounts of artichoke boiled in water. Check canned product ingredients to exclude potentially problematic additives.

(Group 4 — Fish)

If no fish, or only a limited range of species, was eaten during elimination, gradually reintroduce the fish normally eaten.

Preferably start with leaner species lower in taurine, such as haddock, halibut or whiting. Then try fish richer in taurine, such as cod, and/or fattier fish, such as sardines, mackerel and salmon. Test each new species separately.

Choose exceptionally fresh fish and, where possible, initially prefer fish frozen at sea directly on board the vessel.

Group 5 — Eggs

Start with a small amount, for example half an egg, before moving to a whole egg if well tolerated. For this first reintroduction, choose a simple preparation, such as a soft-boiled, poached or fried egg with a runny yolk.

Group 6 — Asparagus

Start with fresh asparagus thoroughly cooked in plenty of boiling water. Test canned asparagus separately, after rinsing it thoroughly and checking for the absence of sulfites or other sulfur-containing additives.

Group 7 — Dairy products

Start with an aged goat's or sheep's tomme cheese, naturally very low in lactose. Continue with yoghurt, then cream and butter. Initially eat small amounts of cream and butter, increasing portions gradually if well tolerated.

If aged hard cheeses are well tolerated but yoghurt or cream seems to cause symptoms, lactose intolerance may be considered.

Group 8 — Alliums

Reintroduce alliums in this order: well-cooked leek, well-cooked onion, then well-cooked garlic. Garlic, which generally causes stronger reactions, should therefore be tested last.

Before further cooking, for example in a frying pan, the leek may be blanched in boiling water for 1 to 2 minutes and then drained.

(Group 9 — Seafood: crustaceans and molluscs)

Seafood reintroduction may start with prawns, which are generally lower in taurine than octopus or squid. Oysters, mussels and scallops, with substantially higher taurine contents, should be reintroduced later. Prawns must not contain sulfites; preferably choose frozen prawns.

Group 10 — Starchy foods: cereals such as (wheat) and oats, and pseudocereals such as buckwheat and quinoa

Preferably reintroduce wheat as heritage varieties and sourdough bread, starting with a small portion without any other newly reintroduced food.

Increase the amount gradually if no significant reaction occurs. Reintroducing wheat, and gluten more generally, is never compulsory. It must be considered individually, as it may be problematic for some people.

Oats may also be reintroduced gradually, followed by buckwheat and quinoa, both in moderation. Before cooking, rinse quinoa thoroughly; soaking for no more than 3 to 4 hours may improve digestive tolerance by removing some of its saponins.

Caution: reintroduce wheat, oats, buckwheat and quinoa gradually and methodically, one food at a time. Monitor digestive reactions carefully, as these foods may be poorly tolerated by some people with digestive disorders, particularly irritable bowel syndrome (IBS).

(Group 11 — Alcohol)

Alcohol reintroduction is entirely optional and is never a compulsory part of the protocol. If desired, consumption must remain occasional and strictly moderate.

If desired, start with a very small amount of a simple spirit such as whisky or rum, and/or wine without added sulfites. Test beer last.

Beer may combine several factors that can trigger a reaction: alcohol, residual fermentable carbohydrates (maltose), compounds produced by fermentation, and variable amounts of sulfates.

Reintroduction options: cautious approach or “flash test”

Test each food separately, without introducing another food at the same time, even within the same group. Two reintroduction options may be considered according to digestive sensitivity.

Option 1 — Cautious reintroduction

Prefer this approach for particularly sensitive people or those who have previously experienced significant reactions:

- Day 1: 1/4 portion
- Day 2: pause
- Day 3: 1/2 portion
- Day 4: pause
- Day 5: 1 usual portion, only if there was no significant reaction to the previous amounts
- Day 6: observe for 24 hours without introducing a new food.

If mild symptoms occur at half a portion, do not increase the amount on day 5. Test a full portion later, after reintroducing the different groups.

Option 2 — “Flash test” reintroduction

This approach provides an initial rapid tolerance test:

- eat half a portion of the food being tested;
- observe any reactions over the following 24 hours;
- if there is no significant reaction, move to the next food.

The “flash test” is a rapid tolerance test, but it cannot confirm tolerance to a full portion.

Example portions for food reintroduction:

Food	¼ portion	½ portion	Usual portion
Cooked broccoli	35–40 g	75 g	150 g
Lean veal	35–40 g	75 g	150 g
Egg	½ egg	1 egg	2 eggs
Asparagus (medium-sized)	1–2 units	3–4 units	6 units
Aged cheese	7–10 g	15 g	30 g
Cooked leek	20 g (cooked weight)	40–50 g (cooked weight)	100–120 g (cooked weight)
Cooked garlic	¼ clove	½ clove	1 clove
Prawns (medium-sized)	2 units	4 units	6–8 units
Sourdough bread	15 g	25–30 g	50–80 g

u = unit

If a significant reaction occurs, temporarily stop food reintroduction, wait at least 48 hours and return to the last well-tolerated diet until symptoms have fully stabilised before restarting reintroduction.

Keep a detailed food diary throughout reintroduction. Record the foods reintroduced, the amounts eaten and tolerated, and any symptoms.

In particular, monitor and record:

- digestive symptoms: diarrhoea, sulfur-smelling gas, intestinal pain, bloating, reflux, etc.;
- symptoms outside the digestive system: headache, a feeling of poisoning or malaise, joint or muscle pain, flushing or skin redness, hot flushes, night sweats, low blood pressure, faster or slower heart rate, marked fatigue, brain fog, anxiety, mental agitation, urinary symptoms, etc.

This record will help identify the foods and amounts associated with symptoms and gradually establish individual tolerance thresholds.

Adapting reintroduction order and diet to the microbial profile (microbiota analysis)

Where the person's microbial profile is known through intestinal microbiota analysis, reintroduction order and dietary advice may also be adapted and personalised.

- If *Bilophila* is excessive, primarily delay foods rich in saturated fat, particularly dairy fats (cream and butter), fatty cheeses, red meat and processed meats. These foods stimulate bile secretion and may increase the availability of taurine-conjugated bile acids. Among seafood, reintroduce high-aurine foods later, particularly molluscs such as mussels, oysters and scallops, as well as octopus and squid. Pay particular attention to possible chronic arsenic exposure: some studies report an association between exposure to this toxic metalloid and greater abundance of *Desulfovibronaceae*, particularly *Desulfovibrio* and *Bilophila* [Brabec JL. et al., 2020, *Heliyon*]. Cereals and pseudocereals are major dietary sources of inorganic arsenic, with rice a major contributor. Brown and semi-brown rice generally contain more arsenic than white rice, as it concentrates in the outer grain layers, particularly the bran. White basmati rice from India or Pakistan often has lower levels, although these vary by growing region and batch. The PBA (Parboiled and Absorbed) method involves precooking rice in one water, discarding it and finishing cooking in fresh water. It may reduce inorganic arsenic by around 54% in brown rice and up to 73% in white rice [Menon M. et al., 2021, *Sci. Total Environ.*].
- If *Fusobacterium*, *Escherichia coli*, *Klebsiella* or *Proteus* is excessive, prioritise delaying foods concentrated in cysteine and methionine, particularly eggs, red meat, processed meats and high-protein dairy products such as skyr and aged hard cheeses. Soy and quinoa may also be reintroduced later. For dairy, consider starting with small amounts of yoghurt or fresh cheese.
- If *Desulfovibrio* is excessive, pay particular attention to sources of sulfate and sulfites, as well as sulfated polysaccharides such as carrageenans E407 and E407a and supplemental chondroitin sulfate. Reintroduce ultra-processed foods, processed meats, dried fruit treated with sulfites/sulfur dioxide, certain alcoholic drinks and high-sulfate waters cautiously. Also avoid a diet high in animal and saturated fats and simple sugars, and low in fibre, which may favour the ecological niche of *Desulfovibrio*. As with *Bilophila*, the abundance of some H₂S-producing bacteria, particularly *Desulfovibrio*, might increase with chronic arsenic exposure [Brabec JL. et al., 2020, *Heliyon*]. In this context, PBA (Parboiled and Absorbed) rice cooking, intended to reduce arsenic content, is also recommended when *Desulfovibrio* overabundance is identified.

FACTORS FAVOURING INTOLERANCE TO SULFUR-CONTAINING COMPOUNDS AND ADVANCED MANAGEMENT STRATEGIES

Intolerance to sulfur-containing compounds may be promoted by a greater load to process or slower elimination. Genetic background, enzyme cofactors and metabolic signals modulate this balance, alongside H₂S production by the microbiota.

Factors favouring sulfur metabolism imbalances and H₂S and sulfite accumulation

- Dietary intake and enzyme cofactors: cystathionine beta-synthase (CBS) and cystathionine gamma-lyase (CTH or CSE) depend on substrate availability. Active vitamin B6, pyridoxal-5-phosphate (PLP), is a cofactor for both enzymes, and S-adenosylmethionine (SAM) activates CBS. High sulfur-containing amino acid intake or supplements such as N-acetylcysteine (NAC) increase the amount of substrates to metabolise (Sbodio J. I. et al., 2019).
- Oxidative stress and inflammation: inflammation and cellular stress responses, particularly via NRF2 and ATF4, may increase CBS or CTH expression. Oxidative stress may also activate CBS through glutathionylation. Endoplasmic reticulum or Golgi stress and amino acid deprivation may induce CTH. These adaptations initially support glutathione production; they may increase the elimination load when more H₂S is produced (Niu W.-N. et al., 2015; Sbodio J. I. et al., 2019).
- Hormones and bile acids: glucocorticoids may increase hepatic CBS expression, while insulin exerts an inhibitory effect. In studied models, reduced growth hormone (GH) or thyroid hormone signalling promotes hepatic H₂S production. Certain bile acids also stimulate CTH through FXR or TGR5 receptors, the latter also called GPBAR1 (Hine C. et al., 2017; Ratnam S. et al., 2002; Renga B. et al., 2009, 2015).
- Slower sulfite processing: sulfite oxidase (SUOX) converts sulfites into sulfates. Acquired molybdenum deficiency, impaired synthesis of its cofactor or a genetic alteration in SUOX may slow this conversion and promote the accumulation of reactive sulfite intermediates (Abumrad N. N. et al., 1981).
- Limited H₂S elimination: mitochondrial H₂S oxidation involves sulfide quinone oxidoreductase (SQOR), persulfide dioxygenase (ETHE1) and thiosulfate sulfurtransferase (TST). Defects in these enzymes, coenzyme Q10 deficiency or limited oxygen may slow elimination. At high concentrations, H₂S may itself inhibit mitochondrial respiration and worsen the imbalance (Libiad M. et al., 2019; Ziosi M. et al., 2017).
- Cysteine oxidation: insufficient cysteine dioxygenase (CDO1) activity reduces direct cysteine oxidation and leaves more substrate available for H₂S production by CBS and CTH. The distribution of cysteine between glutathione, taurine and H₂S therefore influences the load to process (Jurkowska H. et al., 2014).

- Microbiota and diet: dysbiosis enriched in H₂S-producing microorganisms increases the intestinal load even when human enzymes function normally. These microorganisms use sulfates, sulfites, sulfur-containing amino acids (methionine and cysteine) and taurine derived from bile acids. Tetrathionate, formed by thiosulfate oxidation, may be used by some intestinal bacteria as a substrate for microbial H₂S production. Dietary sulfur-containing compounds such as sulfoquinovose may also be degraded by the intestinal microbiota to sulfur-containing metabolites. These can then be used by other bacteria, such as *Bilophila wadsworthia*, to produce H₂S through metabolic cross-feeding. In general, an animal-based diet low in fibre may increase microbial H₂S production (Devkota S. et al., 2012; Teigen L. et al., 2022; Hanson B. T. et al., 2021; Barrett and Clark, 1987).

Genetic variants (SNPs) and metabolic consequences

Gene	SNP	Metabolic consequences of the SNP
CBS	rs5742905 / p.Ile278Thr	Activity ↓; CBS-derived H ₂ S potentially ↓, but homocysteine ↑ → mixed effect on tolerance
CTH	rs28941785 / p.Thr67Ile	Activity and B6 binding ↓; CTH-derived H ₂ S ↓, cystathionine ↑ → mixed effect on tolerance
SQOR	rs762256045 / p.Glu213Lys	H ₂ S oxidation ↓; accumulation promoted → metabolic H ₂ S tolerance ↓
ETHE1	rs745656120 / p.Arg163Gln	Persulfide oxidation ↓; H ₂ S elimination slowed → metabolic H ₂ S tolerance ↓
SUOX	rs121908007 / p.Arg217Gln	Sulfite-to-sulfate conversion ↓ → metabolic sulfite tolerance ↓

↑ increase; ↓ decrease. Expected metabolic direction varies according to the gene copies affected; several variants are rare. Variant source: ClinVar (National Center for Biotechnology Information, undated).

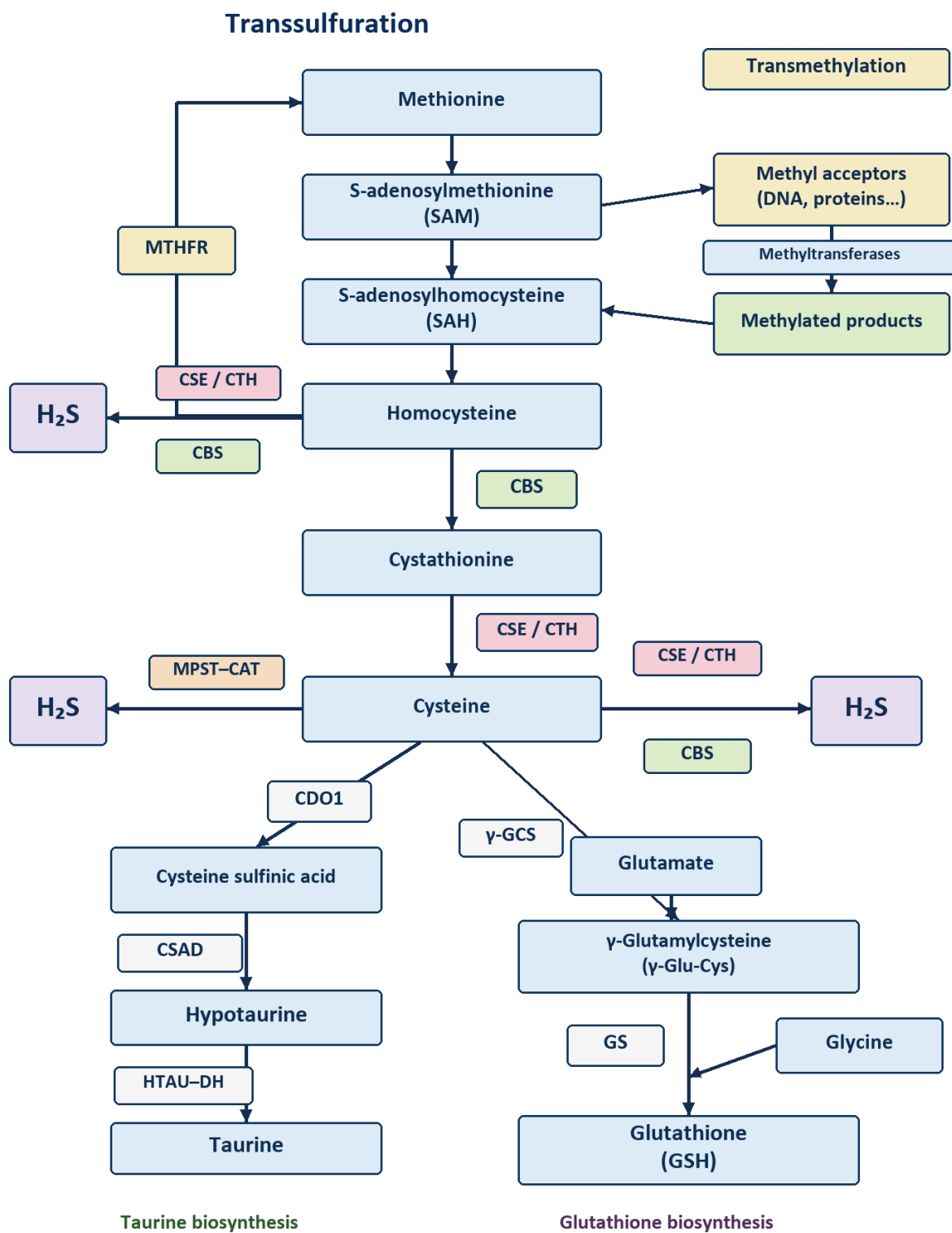
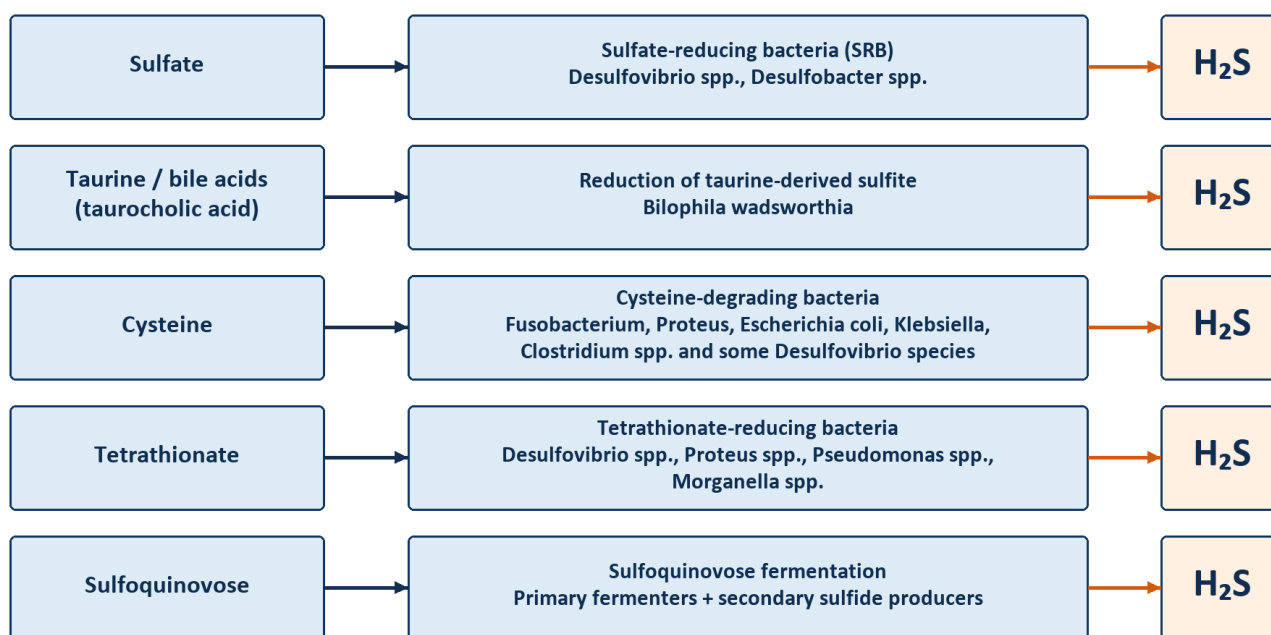


Figure 1. Overview of the transsulfuration pathway and its role in H₂S, taurine and glutathione biosynthesis (adapted from Sbodio et al., 2019).

Figure 2. Main substrates and metabolic pathways involved in microbial intestinal hydrogen sulfide (H₂S) production



Strategies to regulate sulfur metabolism and H₂S and sulfite load

Modulating endogenous H₂S production when needed, and supporting H₂S and sulfite metabolism

Cystathionine beta-synthase (CBS) and cystathionine gamma-lyase (CTH or CSE) use active vitamin B6, pyridoxal-5-phosphate (PLP). Greater activity may increase H₂S production when substrates are available and elimination does not keep pace. B6 modulates this flux; intake should therefore be adjusted to needs rather than increased systematically (DeRatt B. N. et al., 2014). Red ginseng reduces CBS/CTH expression in some cellular models. Linatine in flaxseed gives rise to an active-vitamin-B6 antagonist capable of slowing both enzymes in rat experiments. Its effect involves biochemical antagonism of B6 rather than simply reduced intestinal absorption. If its use is considered, use ground flaxseed and consume it immediately after grinding (Choi K.-S. et al., 2012; Mayengbam S. et al., 2016).

Hydrogen sulfide elimination involves sulfide quinone oxidoreductase (SQOR), persulfide dioxygenase (ETHE1), thiosulfate sulfurtransferase (TST) and sulfite oxidase (SUOX). SQOR uses B2 and coenzyme Q10, ETHE1 uses iron, and SUOX uses a molybdenum-containing cofactor. Correcting a genuine molybdenum deficiency helps sulfite processing; restoring deficient coenzyme Q10 supports H₂S oxidation (Abumrad N. N. et al., 1981; Ziosi M. et al., 2017).

Modulating endogenous H₂S production, particularly by attempting to slow CBS and CTH activity, should be considered when there are grounds to suspect excessive transsulfuration activity. Supporting sulfite-to-sulfate conversion and mitochondrial H₂S oxidation is, by contrast, broadly recommended. Molybdenum and coenzyme Q10 contribute to these processes respectively. Correcting any iron and B2 deficiencies is also essential to support H₂S elimination.

Modulating microbial H₂S production and reducing producer microorganisms

FLSDiet® aims to adjust sulfur-containing compound intake while taking the intestinal microbiota into account and preserving nutritional balance. Its objective is to reduce intestinal H₂S production and limit the overgrowth of certain H₂S-producing bacteria.

Plant bioactives and polyphenols

Several plant-derived polyphenols and bioactive compounds show potential interest for dysbiosis associated with excess H₂S production, particularly through modulation of the intestinal microbiota and reduction of certain H₂S-producing bacteria. A combination of at least two active compounds is generally used in practice.

- Apigenin and derivatives: apigenin-7-O-glucoside improved intestinal barrier integrity, reduced inflammation and favourably modulated the microbiota, notably reducing *Desulfovibrio* abundance, in a mouse model of DSS-induced colitis (Hu Y. et al., 2023).
- Resveratrol: experimental studies suggest favourable modulation of the intestinal microbiota. A study in mice fed a high-fat diet reported lower *Desulfovibrio* abundance alongside increases in short-chain fatty acid (SCFA)-producing genera such as *Blautia* and *Allobaculum* (Wang P. et al., 2020).
- Jiaogulan (*Gynostemma pentaphyllum*): this plant contains triterpene saponins, particularly gypenosides, which are not polyphenols. Experimental studies show potential to favour beneficial bacteria and reduce sulfate-reducing bacteria (SRB), which may contribute to intestinal H₂S production (Chen L. et al., 2016).
- Pomegranate extracts (*Punica granatum*): rich in ellagitannins, particularly punicalagins, and ellagic acid, these have anti-inflammatory and microbiota-modulating properties. Their potential interest for H₂S-associated dysbiosis rests partly on reported inhibition of bacteria such as *Escherichia coli*, *Klebsiella* spp., *Shigella* spp. and *Clostridium* spp. (Buccato D. G. et al., 2025).
- Oregano essential oil: in vitro antimicrobial activity has been demonstrated against several *Pseudomonadota* (formerly *Proteobacteria*), particularly *Escherichia coli*, *Proteus* spp. and *Pseudomonas* spp. (Sienkiewicz M. et al., 2012; Nguyen H. L., 2025). An experimental chicken study also found reduced *Bilophila* abundance in the caecal microbiota (Wu T. et al., 2022). Oregano essential oil is a more aggressive and less selective antimicrobial approach than some other plant bioactives. At high doses, it may also affect beneficial intestinal bacteria, particularly *bifidobacteria*.

Other approaches

- Bismuth subsalicylate has a strong capacity to trap intestinal H₂S. One study found that oral administration for 3 to 7 days reduced faecal H₂S concentrations by more than 95% (Suarez F. L. et al., 1998). Bismuth subnitrate is another commonly used form. Bismuth must be used under medical supervision. It may reduce *Desulfovibrio* abundance but may also favour other *Pseudomonadota* (formerly *Proteobacteria*), particularly *Enterobacter*, *Escherichia* and *Klebsiella*. It is therefore not necessarily appropriate for every H₂S dysbiosis profile. Combining it with pomegranate extracts may be considered to limit expansion of these bacteria.

Appendices

Appendix 1 – Bottled waters low in sulfates

- France: Volvic (9 mg/L), Evian (15 mg/L), Thonon (12 mg/L), Wattwiller (34 mg/L), Cristaline (47 mg/L)
- United States: Poland Spring, Iceland Glacial, Fiji water, Aquafina 5 (purified water)
- Spain: Bezoya, Mondariz, Castrovita, Aquarel, Solán de Cabras

Appendix 2 — Probiotic bacteria that may produce H₂S

This non-exhaustive list includes probiotic bacteria shown experimentally to produce hydrogen sulfide (H₂S) in vitro, particularly when cysteine and/or methionine are present as sulfur-containing substrates. Names in parentheses follow the revised nomenclature published in 2020.

- *Lactobacillus plantarum* 299V (*Lactiplantibacillus plantarum* 299V)
- *Lactobacillus rhamnosus* GG (*Lacticaseibacillus rhamnosus* GG) *
- *Lactobacillus reuteri* BR11 (*Limosilactobacillus reuteri* BR11)
- *Lactobacillus delbrueckii* ATCC4797
- *Bacillus subtilis*?

References: Sreekumar R. et al., 2009; Tyulenev A. et al., 2024.

* Although *L. rhamnosus* GG is classified among probiotics that may produce H₂S in vitro, it is generally well tolerated by people with ISO. Some animal studies (*L. rhamnosus* GG alone or co-administered with *Bifidobacterium animalis* subsp. *lactis* BB12) and human studies (co-administered with a prebiotic fibre) have found a reduction in H₂S-producing bacteria in the microbiota, such as *Bilophila wadsworthia* and *Desulfovibrio* spp.

References: Ni Y. et al., 2017; Lin YC. et al., 2022; Costabile A. et al., 2017.