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Expert Panel on Livestock Methane

Potential of animal feed additives for methane mitigation

Summary

This is the first in a series of briefings looking at what the latest science tells us about different approaches to reducing livestock methane - which currently contributes up to 32% of methane from human activity.

This briefing will focus on the efficacy of different feed additives as a methane mitigation tool for livestock.

- All feed additives tested to date show highly variable methane reduction potential. This makes it difficult to confidently say how much methane they will be able to mitigate.
- Variability in methane reduction potential across studies can result from differences in what the animals are being fed and how this feed is administered, the breed and species of animal, the condition of the animal, the dose of the feed additive and its source and quality, with all of these variables interacting in complex ways.
- Red seaweed and 3-nitrooxypropanol (marketed as Bovaer) are most promising for methane mitigation in ruminants, but come with various uncertainties and disadvantages.
- While red seaweed has been reported to reduce methane emissions by up to 99% in test-tube studies, the longest available trial to date found only a 28% reduction in wagyu cows. Animal weights at the end of the trial were also lower, meaning that the overall methane intensity - the methane produced per unit of meat or milk - was no different between the cows that were supplemented and those that were not.
- 3-Nitrooxypropanol reduces methane emissions by an average of 30%, with lifecycle assessments reporting up to 14% decreases in whole-farm dairy net greenhouse gas emission intensity. However, some studies have found that its efficacy may decline with time.
- A major challenge with feed additives is that they have to be administered frequently because they break down rapidly in the human. So while they can easily be administered to animals in feedlots, it is currently not possible to effectively administer them to livestock on pasture—where most livestock spend their lives.
- While Bovaer has been tested extensively for animal welfare and food safety, the active ingredient in red seaweed is bromoform, a known animal and probable human carcinogen. This could pose barriers to regulatory approval and consumer acceptance.
- All feed additives require more testing in longer-term trials and under a variety of experimental conditions—such as in different animal breeds or with different feeds—to fully assess their efficacy over an animal's lifetime.
- Lifecycle assessments are important for quantifying the net climate change effects of interventions such as feed additives, yet few have been reported.
- All feed additives imply an additional cost to farmers, with uncertain price implications. Climate policies incentivising the use of methane-reducing feed additives will be critical to achieving environmental gains.

Reducing digestive methane emissions with feed additives

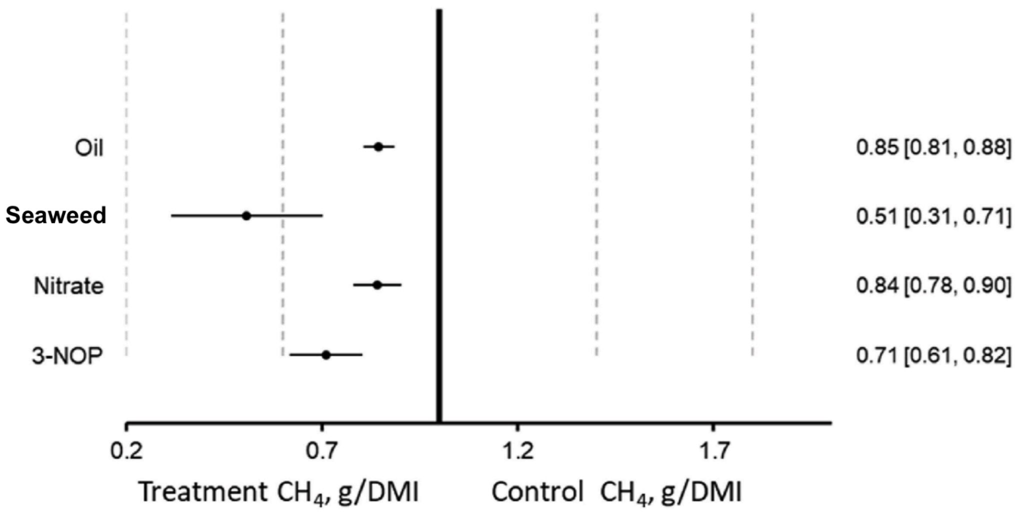
Ruminant animals, such as cows, sheep, buffaloes and goats, ferment plant matter in a specialised stomach called a rumen during digestion. In the rumen, plant matter is first broken down into simple sugars, which are then broken down by various microbes into carbon dioxide, hydrogen, and volatile fatty acids, among other products. Single-celled organisms called methanogens use these breakdown products to produce methane in a process called methanogenesis, which improves the efficiency of the digestive system and avoids the negative impacts of a build-up of hydrogen on vital biological processes.

The methane resulting from methanogenesis is not used by the animal and is released into the atmosphere mainly through belching.

Inhibiting methanogenesis in the rumen is key to lowering animal methane emissions, but it is important to strike a balance between reducing methane emissions and limiting the negative impacts of hydrogen buildup on animal health and performance.

Methane-inhibiting feed additives work by disrupting the methanogenesis pathway or by modifying the rumen environment—for example, by making less hydrogen available for methane production. Other hydrogen elimination pathways besides the methane pathway can be used in the gut when methanogenesis is disrupted, but the extent to which hydrogen is disposed of via alternative pathways varies across feed additives. Therefore, it is important to carefully manage feed additives and ensure that alternative pathways are available for hydrogen disposal.

Figure 1. Forest plot showing average methane reduction values (black points) and the 95% confidence interval (horizontal lines) for four feed additives from a meta-analysis published in *Animal Nutrition* in 2021. The further away the values are to the left from the vertical centre line, the better the methane mitigation effect. The confidence interval shows the range of methane mitigation potential with 95% confidence. Additives with low reduction potential that were not included in this article have been excluded from this reproduction of the plot.



Red seaweed

Of the various feed additives, one that has shown the greatest methane reduction potential and received widespread media attention is red seaweed, particularly the species *Asparagopsis taxiformis* (Figure 1). The active ingredient in the seaweed is bromoform, a chemical which has long been known to inhibit the metabolic activity of methanogens. Numerous *in vitro* or 'test-tube' studies – whereby a sample of rumen fluid is supplemented with red seaweed or bromoform in a flask and the amount of methane released is measured – have reported methane emission reductions of up to 99%.

While informative, test-tube studies can only give limited insight into the efficacy of the additive because they do not reflect the entirety of the complex ruminant digestive process. Microorganisms are also able to adapt to changes in feeding regimes, meaning that short-term responses during studies do not necessarily reflect the effects of a supplement in real farm conditions over the long-term. By contrast, *in vivo* or animal trials – which offer better insight because they directly feed cattle red seaweed and measure methane production by the animal, typically for several to many weeks – have shown far more variable results. Some of these results are summarised in Table 1 below.

Table 1. Published *in vivo* trials supplementing feed with red seaweed. Table adapted from here.

Animal	Feed type	Trial length	Seaweed inclusion rate	Methane reduction
Brangus beef steers	High grain	90 days	0.05% 0.10% 0.20% 0.25%	9% 38% 98% 50.6%
Angus-Hereford beef steers	Forage ration	147 days	0.50%	74.9%
Holstein-Friesian dairy cattle	Vetch hay and grain mix	27 days	0.56% 0.64%	44% 39%
Holstein dairy cattle	National Research Council formula	28 days	0.50%	29%
Holstein dairy cattle	Formulated mixed ration	14 days	0.50% 1%	26.4% 67.2%
Merino-cross wethers	High-fibre pellets	72 days	0.50% 1% 2% 3%	6% 19% 25% 29%

Additionally, the longest and largest commercial animal trial to date, conducted by Meat & Livestock Australia – an independent company that regulates standards for livestock and meat management – tested the use of *Asparagopsis* for methane reduction in cattle by supplementing 40 wagyu cows with *Asparagopsis* extract in canola oil over 275 days. This achieved a methane reduction of 28%. The trial also found that the cattle ate less feed and had gained less weight than normal at the end of the trial period. This meant that the overall methane intensity - the methane produced per unit of meat or milk - was no different between the cows that were supplemented and those that were not. So, no methane reduction but considerable additional cost.

The results of animal trials suggest that the effectiveness of red seaweed supplementation varies depending on many factors, such as the type of feed used in conjunction with the additive, how the feed is administered, the species and breed of the animal and its condition (e.g. stress levels, which have not been routinely tested in studies). The amount of bromoform in red seaweed - which is often not reported in studies - makes it difficult to determine whether the variability in results stems from different quantities of the compound used in test feed. Natural populations of the seaweed contain variable amounts of bromoform due to factors such as genetics and environmental conditions.

The cultivation, preparation and harvesting of red seaweed have also proven difficult because of its complex reproduction characteristics, which could hamper the scaling-up of seaweed supplies for commercial production in the near term. The seaweed is also considered invasive in some areas, posing a risk to ecosystems if not cultivated responsibly. Synthetic bromoform can be readily synthesised in the laboratory and produced at scale, but it will need to be carefully managed given its ozone-depleting potential.

There are also concerns about the health of animals supplemented with red seaweed, with some studies reporting adverse effects such as rumen inflammation and ulceration. Bromoform is a known animal and probable human carcinogen that has not been found at significant levels in the meat or milk of supplemented animals. Changes to the milk of dairy cows supplemented with red seaweed have also been reported, including increased bromine and iodine levels - the latter linked to thyroid dysfunction, and changes to the fatty acid profile. In one analysis, the quantity of iodine present in one cup of milk from red seaweed-supplemented cows exceeded the upper limit for children.

While careful dose management may be able to reduce direct health effects on animals and in food products, the introduction of a known animal carcinogen into the food chain may raise regulatory barriers and consumer concerns that could limit its overall adoption. The cost of large-scale production and administration of red seaweed as a methane-reducing feed additive is not yet known.

As with many feed additives, bromoform is metabolised very quickly - 90% of bromoform degrades within the first three hours and more than 99% degrades after 12 hours when feeding both high-forage and high-concentrate diets - it needs to be administered frequently. This is impractical for animals in typical beef production systems in major beef-producing countries such as the US and Canada, where a permanent herd is usually kept on pasture in order to produce calves - around 80% of methane in these systems is produced by these grazing cows and calves.

3-NOP

Another supplement with good methane reduction potential is 3-nitrooxypropanol/3-NOP, marketed as Bovaer. It reduces methane emissions from ruminants by an average of 30% (Figure 1), with better results in dairy cattle compared to beef cattle at the same dose. It has been evaluated in a large number of scientific studies and on-farm trials and has received regulatory approval in many countries, including Brazil, Chile, Australia, the UK and the EU, and is already used by dairy producers such as Bel Group, Valio, and Arla Foods.

The animal trial results are summarised in Table 2 here and show highly variable methane reduction results - ranging from just 4% to 76% - depending on the diet, dose and the length of the trial. Dietary differences are believed to be one of the main reasons for variations in methane mitigation between dairy and beef cows. Diets high in fibre - such as certain grasses - tend to produce more methane.

Lifecycle assessments - which evaluate the emissions at various stages of agricultural production - are important for quantifying the net climate change effects of an intervention such as feed additives, yet few have been reported for the additives discussed here. For 3-NOP, lifecycle assessments have modelled 11.7% and 12% (US), 14% (Australia) and 15% (Canada) decreases in whole-farm dairy net greenhouse gas emission intensity. For beef farms, 3-NOP has been found to reduce whole-farm greenhouse gas emissions by 19% (Canada) and 23% (Australia).. The authors further note that these results are "highly theoretical and speculative" as there was no data on the effect of 3-NOP on mature beef cows at the time of analysis, meaning that they had to extrapolate from growing cows fed a high forage diet. The effects of the supplement on these two groups may be different. The reason for the lower methane emissions reduction potential in lifecycle assessments compared to emissions reductions from supplementation alone is mainly because livestock systems generate not only methane from enteric fermentation but also from manure management, as well as other greenhouse gases, which are not reduced by 3-NOP.

3-NOP has consistently been found to have low safety risks, with minimal to no residues detected in milk or meat, and its metabolic byproducts are not known to be toxic. Like other feed additives, it is also rapidly metabolised - 54% of 3-NOP remains in animals at six hours and is eliminated from the animal by 24 hours meaning it needs to be administered frequently, making it impractical for pasture-reared animals.

Modest improvements in milk fat and protein composition in dairy cattle and feed conversion efficiency in beef cattle have been reported in some studies supplementing 3-NOP. These may offset the cost of using 3-NOP, but the degree to which costs are offset is likely to be highly variable.

Some long-term trials have found that the methane mitigation effect of 3-NOP decreases with time, suggesting that the rumen may be adapting to the supplement. However, other studies show no decline in the mitigation effect. Longer-term trials over multiple years and over multiple lactations in dairy cattle are still needed to ensure that the mitigation effect of 3-NOP remains consistent. One year-long trial over multiple lactations in dairy cows found that the efficacy of 3-NOP declined over time - though not continuously - and that diet composition had a major impact on this.

3-NOP is not yet available as an over-the-counter product, and overall quantities are limited. Its availability and cost at this point therefore depend on direct arrangements with the supplier.

Other supplements

More modest methane reductions have been reported for other supplements. For example, **garlic and citrus** extracts have been shown to reduce methane emissions in ruminants in animal trials, though the effects are inconsistent across studies, and the mode of action is unclear. Additionally, a summary of studies and trials of garlic and citrus oils and extracts on methane inhibition (found in Table 2 here) shows substantially lower methane reduction for animal trials compared to test-tube studies.

The variability among studies is likely related to the different levels of active ingredients in garlic and citrus - which would vary naturally due to the genetics and environmental conditions of the plants, including how they are cultivated and processed, and the different feeds being used and how they interact with the extracts.

One animal trial found no significant difference in average methane production between steers supplemented with a garlic and citrus extract called Enterix developed by the feed additive company Mootral, and unsupplemented steers over a 12-week period. However, the authors believe that this was due to the animals avoiding the supplemented pellets in the first few weeks of the experiment. If only the final week is considered - when the steers were seen to be consuming the supplemented pellets - a 23% decrease in methane was recorded.

A lifecycle assessment conducted in part by Mootral's scientists found that feeding Mootral's garlic and citrus extract to grazing dairy cows on a Chilean dairy farm reduced the emissions intensity of the milk by 8.39% and improved milk parameters.

Mootral is seeking regulatory approval for its new formulation (Enterix Advanced) that combines its garlic and citrus extract with the antiseptic compound **iodoform**. An animal study supplementing cattle with iodoform alone decreased methane emissions by up to 66%, but also decreased the amount of food eaten by 48% and milk production by 33%. No ill effects on cow health were detected in the study. The carcinogenic potential of iodoform has not been sufficiently evaluated. While exposure has been linked to slightly increased tumor risk in male rats in one study, another study found no statistically significant association between exposure and carcinogenicity in rats or mice. Enterix Advanced's maker claims its product reduces methane emissions by up to 50% without the associated changes in feed intake and milk production when using iodoform alone. With no relevant studies published in scientific journals at the time of writing, it is difficult to assess the efficacy of this new approach.

Feeds containing **nitrates** decrease methane emissions by an average of 15.7%, with a lifecycle assessment reporting a 4.8% reduction in the milk carbon footprint on a dairy farm. However, nitrate toxicity - including potential cancer-causing compounds - poses a major barrier to nitrate supplementation. Feeds high in nitrates could increase N2O emissions from animal waste.

Adding **oils** to feed can reduce methane emissions by an average of 15%, but has been found to reduce feed intake as well as fibre digestibility in high-fibre diets, but not low-fibre diets, meaning that oil supplementation may not be appropriate for grazing animals. It has also been found to reduce milk production by up to 13.7%.

Supplementing pasture-reared animals

The private sector has responded to the issue of the rapid degradation of additives in the rumen by developing a sustained-release capsule, or bolus, containing an undisclosed methane inhibitor that is released in the rumen. Though still in the development stage, the producer aims to have a commercially viable bolus by 2025. However, it is not possible to evaluate how realistic this claim is based on the available data. Mootral's Enterix Advanced is also a controlled-release formulation that has been developed with grazing cattle in mind and has been modified from its earlier formulation - by using garlic oil as opposed to garlic powder - to fit into a bolus.

Despite these announcements, there is still no effective means available for constantly supplying methane inhibitors to animals on pasture.

Long-term effectiveness of methane inhibitors

There are also concerns around the adaptation of rumen gut microbes to feed additives that could result in a decrease in methane inhibition efficiency with time. While long-term animal trials of red seaweed supplementation in sheep and cattle have found that bromoform consistently reduces methane emissions, another animal trial using a similar methane-inhibiting compound, chloroform, found that following an initial rapid decline, methane emissions increased slowly over the experimental period despite the dose remaining the same. Similarly, some long-term trials have found that the methane mitigation effect of 3-NOP decreases with time, while others have noted a consistent effect.

Summary

All of these additives vary substantially in their methane mitigation potential, meaning that it is difficult to confidently say how much of current emissions they will be able to reduce. This is largely because the ruminant digestion process is complex and is influenced by a number of external factors relating to the feed, the breed and physiology of the animal - such as age, genetics and condition - and the quality of the supplement, such as the natural variation in the levels of the active ingredient. Differences in methane emissions reported in studies could also be partly explained by the different techniques used to measure methane.

No effective means of providing a regular supply of methane inhibitors to animals on pasture currently exists, meaning that there is no way to reliably supplement the majority of livestock. Another concern is the potential reduction in the efficacy of methane inhibitors as rumen microbes adapt to supplementation over the long term. More studies testing the interactions of different variables are needed to offer robust long-term estimates of their mitigation potential and of their costs, benefits and risks.

The Expert Panel on Livestock Methane works together on a voluntary basis to bring the latest peer-reviewed science to the media and policy debate about livestock and climate change.