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Stakeholder Opinions of Seaweed Supplements for Dairy Cows

Autumn Moen
University of Vermont

David Conner
University of Vermont

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ABSTRACT

Addressing methane emissions from livestock is crucial for agricultural sustainability, especially in a large industry like diary production. Seaweed supplements, like *Asparagopsis taxiformis*, offer promise in mitigating emissions from cattle without harming productivity. These supplements may also provide an array of other benefits, such as somatic cell reduction in milk, micromineral supplements for general animal health, and improved milk qualities. Little research to date has been conducted to understand how these supplements are being marketed and sold to dairy farms: this information can help ensure these possible benefits will be realized. This study presents findings from a qualitative analysis of dairy feed suppliers in the northeastern United States, providing insights into their perspectives on seaweed supplements. The study explores differences between organic and conventional feed suppliers including their perceived benefits and challenges to feeding seaweed. Primary benefits include micromineral supplementation, reducing somatic cell count, reducing methane emissions, and reducing use of manmade mineral supplements. Barriers to feeding seaweed include price, volume needs of mills, supply inconsistencies, and lack of investment from the industry. Feed suppliers also provided insight into what information they need about seaweed to start recommending it to farmers, if they don't recommend it already. These findings lay the foundation for further exploration of supply chain dynamics and stakeholder considerations in promoting sustainable livestock practices.

INTRODUCTION & LITERATURE REVIEW

A movement towards sustainable agriculture is underway in many parts of the world, as research makes the case that current methods of food production are both contributing to climate change and are

less resilient to a warming planet (Leal Filho et al., 2022). One issue in agriculture with a growing interest is methane emissions from livestock. Ruminant livestock, such as cows and sheep, emit high levels of methane through their digestion process and are the main reason that agriculture is a leading sector for anthropogenic methane emissions globally (Chang et al., 2021). In fact, enteric methane emissions from livestock contributes 6% of total anthropogenic greenhouse gas emissions and is a more potent greenhouse gas than carbon dioxide (Black et al., 2021). Among ruminant species, cattle contribute the most greenhouse gas emissions at 4.6 Gt (Gerber et al., 2013). 3.3 Gt of this can be attributed to methane and nitrous oxide emissions from enteric fermentation and manure alone (Gerber et al., 2013). A transition away from beef and dairy is unlikely for economic and lifestyle reasons, and even so, a transition to more plant-based diets alone would not reduce emissions at the rate necessary to limit global temperature rise (Chang et al., 2021). It is for this reason that researchers have begun to investigate methods for reducing methane emissions from cattle (both beef and dairy).

A variety of methods have been studied for their potential to reduce enteric methane emissions from cattle (Beauchemin et al., 2022). These methods include dietary supplements, genetic selection, microbiome manipulation via diet changes, and increased production efficiency (Carrazco et al., 2020; Chang et al., 2021; Matthews et al., 2019; Pickering et al., 2015; Stefenoni et al., 2021). Among dietary supplements to reduce methane emissions, seaweed has emerged as a supplement with the potential for high enteric methane reduction (Black et al., 2021).

The use of seaweed in cattle feed is not novel; *Ascophyllum nodosum,* a brown seaweed commonly known rockweed, has been used in cattle feed because of the high concentrations of bioactive compounds (Antaya et al., 2019). It is only recently being studied for its methane reduction capabilities (Antaya et al., 2019) along with a variety of other seaweed species such as *Asparagopsis taxiformis, Dictyota bartayresii* (Machado et al., 2014), *Asparagopsis armata* (Roque et al., 2019), *Saccharina latissima, Ulva. Sp., Gigartina sp., Laminaria ocurolueca, Gracilaria vermiculophylla* (Maia et al., 2016) and others (Machado et al., 2014; Min et al., 2021; Molina-Alcaide et al., 2017). *Asparagopsis taxiformis,*

a species of red seaweed, has emerged as the most effective seaweed species for enteric methane reduction (Black et al., 2021; Kinley et al., 2020; Machado et al., 2014; Stefenoni et al., 2021). Most notably, Kinley et al (2020) showed that including *Asparagopsis* into beef feed at the 0.10% and 0.20% rate showed a methane emission reduction of 40% and 98% respectively. Not only did this study show that seaweed supplements are a potential intervention for reducing methane emissions from livestock, but it also showed that the cattle were more productive while eating the seaweed and showed no negative effects (Kinley et al., 2020). Stefenoni et al (2021) also found a 98% reduction in enteric methane emissions in dairy cows who were fed *Asparagopsis taxiformis* at a 1% inclusion rate.

As pressure to reduce greenhouse gas emissions from livestock rises and initiatives to do so expand, emerging research has begun to investigate opinions of various stakeholders regarding these initiatives. Some researchers have conducted studies to assess consumer opinions, preferences, and willingness to pay for meat and dairy that has been sustainably produced (Altmann et al., 2022; De Valck et al., 2023; Li et al., 2023). Others have conducted research on farmers opinions of various on-farm sustainability initiatives (De Lauwere et al., 2015) and various stakeholder opinions of sustainable animal feed options specifically (Makkar, 2014). More recent researchers have investigated farmers opinions on seaweed feeds specifically (Bay-Larsen et al., 2018; Tynan et al., 2023). Bay-Larsen et al (2018) conducted interviews with sheep farmers in Norway to ask about utilizing local protein options in feed, including seaweed. Tynan et al (2023) used a mixed-methods approach to ascertain dairy farmers perceptions and benefits of seaweed feed supplements. The perceived benefits of feeding seaweed asked about in this study include increase in milk yield, source of vitamin C, magnesium, calcium, zinc, reduced somatic cell count, enhanced immune function, increased weight gain, improved fatty acid profile or fat content of milk, and reduced weaning stress (Tynan et al., 2023).

Feed suppliers are a prominent stakeholder in the dairy feed industry because farmers go through them to purchase feed and feed supplements. For mitigation strategies such as seaweed supplements to become widespread and make a meaningful impact on methane emission reduction, insight is needed

from people working throughout the feed supply chain. To date, there are no studies published regarding opinions of dairy feed suppliers on climate mitigation strategies in the livestock sector, nor any studies regarding their opinions on seaweed supplements. This study was conducted as part of a multi-state project aimed at assessing the feasibility of a seaweed feed supply chain from Maine to dairy farmers in the northeast United States. This qualitative study on dairy feed suppliers in the northeast U.S. can serve as a foundation for further supply chain analysis and stakeholder opinion considerations.

METHODS

This study was conducted between October 2022 and January 2023. Participants were chosen through a process of researching dairy feed suppliers in the Northeast United States and reaching out to them via phone call or email. To qualify for the study, the individual needed to work directly with dairy farmers as a feed supplier. The lead author interviewed eight individuals from eight different feed supplier companies in Vermont and New York. Interviews were conducted virtually, using Microsoft Teams, and they lasted between 25 and 45 minutes. Interviews were automatically transcribed within the Teams software. A semi-structured interview guideline was used (available upon request), with flexibility for follow-up questions and clarification when needed.

Once all eight interviews had been conducted, the transcripts were cleaned manually and the data was uploaded to the qualitative data software, NVivo. The lead author conducted open coding on all eight interviews. Once open coding was completed, the codes were sorted under axial codes. Then all eight interviews were recoded to catch missed codes and reassign codes where necessary. At this stage, the codes were reassessed and sorted in the final axial and sub-axial codes.

RESULTS

Responses were grouped into six major themes (axial codes): who currently feeds seaweed, how seaweed it fed, why seaweed is fed, why seaweed is not fed, supply chain, and outlook. The theme of

"why it is fed" is further broken into 2 groups: benefits and current knowledge. The theme of "why it is not fed" is further broken into barriers and what suppliers need in order to recommend. Interviewees may use the word "kelp" in direct quotes, as the current seaweed products on the market generally contain brown seaweed, also known as "kelp". Authors will continue to use the umbrella term "seaweed".

Who currently feed seaweed?

Dairy feed suppliers noted some general themes in the types of farmers that currently use seaweed supplements, or those who have expressed interest in these products. Multiple participants mentioned that farms using these supplements tend to be smaller, and two mentioned selling it to Amish farmers. By and large, the most prominent trend among who feeds seaweed supplements is that organic farms are more likely to use them than conventional farms. One feed supplier said that *"The only kelp that I'm aware of was used on a couple of organic herds"* while another said, *"I haven't* [recommended it] *because it's not an ingredient that's popular with conventional herds".* A third suppler noted: *"it's always organic. We-- I don't think I've ever had a commercial dairy producer asked for kelp".*

Some feed suppliers attributed this difference to the fact that organic farms are often smaller, which makes adding seaweed more feasible, with one supplier saying that *"organic is a much, much smaller industry with much smaller farms".* More often it was attributed to the fact that organic farmers need organic supplements, and seaweed products fit the bill: *"For organic, again, they've got a pretty limited source of microminerals and stuff like that, so kelp is one that they can use. That's why they're educated or have some knowledge of it".* Similarly, some feed suppliers attributed this difference to the values of an organic farmer: they don't want to use man made metal supplements and prefer natural ones. One suppler said *"there's a philosophy, a mindset behind organic that is sort of devoted towards a way of thinking about feeding things that are natural and obviously kelp being just a plant that comes up out of the sea is as natural as it gets".* Another commented on how organic farmers *"maybe have a little bit*

more of a closeness with their animals, if you will, and they're concerned with not allowing the animals to get heavy metals, for example".

This idea that there is a difference between what organic farmers use for supplements and what conventional farmers use came up with all eight feed suppliers. While the suppliers attributed this to a few different reasons – farm size, the need for organic supplements, and values – it was noted by all eight interviewees.

How seaweed is fed

When talking with dairy feed suppliers about seaweed supplements, it became clear that farmers are not always the ones making this decision for their herd. Feed suppliers expressed that often it is dairy feed consultants (DFC's) or nutritionists who make these decisions and that *"it's an interesting thing where umm, the farmer's biggest expense is feed, yet there's the least amount of knowledge on farms about what's going in their feed".* Many suppliers shared that the formulation for a feed is adjusted by nutritionists in order to get certain outcomes, such as high production or increased milk fat.

For those who are using seaweed supplements currently, there are two ways in which is it fed; free choice and mixed into feed. Free choice refers to a situation where a farmer adds the supplement to the top of the feed and cows and take as much as they want. Others include a predetermined amount, usually two oz. per cow per day, into the feed mix. Free choice was the more popular response from the suppliers, and many mentioned mixing it with salt; *"most feed it as a 50/50 blend with plain salt or Redmond salt just to reduce consumption".* Another supplier shared that he uses a blend of *"the kelp meal, Redmond salt and diatomaceous earth. I like to mix that one third each and offer it free choice"*. A few suppliers noted that cows will generally eat as much seaweed as is put out in front of them, hence the need to dilute it with salt to reduce consumption and save on the cost of the supplement. This suggests the supplement is palatable for the cows, at least in the dried form in which it is currently fed.

Reasons for use of seaweed supplements

Feed suppliers expressed a multitude of reasons that diary feed suppliers currently use seaweed supplements, the most prominent being reduced somatic cell count, microminerals & general health, and the potential to reduce manmade supplements. A few other benefits were brought up with less frequency, including reproduction benefits, iodine supplement, hair coat deficiency benefits, and immune function support. Often these additional benefits were attributed to the balanced microminerals and general increase to animal health when on the supplements. It is important to note that while feed suppliers often noted the potential for methane reduction as a benefit, the current seaweed supplements on the market are mostly made using a brown seaweed (*Ascophyllum nodosum*) which is not known to significantly reduce methane emissions.

Somatic Cell Count

The benefit in feeding seaweed that was brought up most frequently by feed suppliers was reduced somatic cell count. One feed supplier explained that "*reduced somatic cell count would be one reason that we have customers request that",* suggesting this is a main reason for the interest in seaweed supplements from dairy farmers. Along similar lines, another interviewee said, "*typically what dairy farms report is anecdotal evidence of lower somatic cell counts*". When asked why a dairy had asked him to supply seaweed supplements, another feed supplier who was less familiar with these supplements said *"this is vague and I really don't remember… I want to say they were trying to reduce somatic cell".* One question in the interview directly asked interviewees if they believe there is evidence to support the claim that seaweed supplements reduce somatic cell count and all eight interviewees said yes.

Microminerals and General Health

The second most frequent benefit mentioned by feed suppliers was that seaweed is a great micromineral source or generally good for animal health. Suppliers noted *"if you feed proper nutrition,*

including microminerals… the cow will be healthier", and *"anytime that a dairy cow's minerals are balanced she's gonna be far more healthy"* suggesting that these two benefits are explicitly linked, and were therefore combined during analysis.

Many of the suppliers interviewed noted that there are animal health benefits to feeding seaweed; "*there is a there's a benefit to feeding it, I feel. And that's reflected in animal health usually".* Some suppliers noted secondary benefits that occur when animals are healthy, such as *"some people… report less hoof problems, hairy wart and other things being reduced".* Multiple interviewees noted an observed reduction in common cow health issues such as pink eye or breeding rate, saying that *"while it's not going to cure pink eye, what we do have people report to us is that keeping kelp in front of the cows all the time severely reduces the incidences of pink eye"* and *"we also hear that people have better breed back when feeding a kelp supplement".* All of the suppliers interviewed mentioned at least two or three different microminerals that they believe to be supplied by seaweed supplements, and most associated these supplements with general improvement in animal health. A few added that when cows have proper nutrition, they *"have a better immune system and therefore make more milk",* which is an added benefit to the farmers.

Potential for Replacing Manmade Minerals

An interesting benefit that was not touched on by all interviewees was the potential for seaweed supplements to be able to replace manmade minerals in feed mixes. Only two interviewees discussed this benefit, but both talked about it extensively and believe this could be a massive benefit of seaweed supplements. Feed mixes for cows often include manmade mineral supplements that are either in raw form or chelated. Chelated minerals are minerals that have been chemically combined with amino acids in order to ease absorption. As one feed supplier put it, seaweed "*is highly digestible and available to the animal where your man-made minerals or 'harvested minerals' if you will, out the soil are not as rumen degradable for these animals so that's what I do like about it".* The suppliers also noted how expensive these manmade mineral supplements can be: "*farmers will spend exorbitant amount of money on chelated*

minerals, those type of things… the minerals, to my knowledge, within kelp, sort of are naturally chelated". For them, this is a reason to support the expanded use of seaweed supplements: "*I haven't heard anything specific but if you showed that by including a kelp additive it would remove the need for this really expensive synthetic amino acid, everybody would be like, 'Ohh, that's great'".*

One feed supplier expressed concern that minerals currently used in feed may have "*some issues… with PCB's and arsenic and heavy metals and stuff like that that are a little bit scary sometimes,"* but that *"something like kelp is natural and doesn't have that".* This supplier associated high concentrations of heavy metals with the fact that these supplements are shipped from overseas, but believes the screening process falls short in catching these toxins: "*when companies talk about screening for the most part they're… I don't wanna say they're lying to you, but they're not screening very much… So, if it's got some level of arsenic or PCB's or heavy metals, it still goes out into the into the feed and nobody cares".* None of the other participants specifically commented on the concern of heavy metals in manmade mineral supplements, it is important to note that two of the interviewees work exclusively in organic feed and therefore do not supply these types of supplements. Another feed supplier exclusively supplies their own line of supplement, and therefore would also not encounter these imported mineral supplements. Among the four purely conventional feed suppliers, this concern came up with half of them.

Potential for methane reduction

The seaweed feed products currently on the market generally contain a brown seaweed, or kelp, commonly called rockweed or "asco" by feed suppliers. This supplement is not currently used to reduce methane, although researchers have begun to assess the potential for methane reduction capabilities (Antaya et al., 2019). Nevertheless, feed suppliers note this potential for methane reduction as a benefit to feeding seaweed: "*the big interest these days is in the compounds that reduce methane production*". Feed suppliers expressed that this is being talked about in their space, with one saying, "*the only thing that I would say* [we are discussing] *internally would be more around algae to reduce belching. It would reduce greenhouse gas. I've heard of that particular path*" and another said, "*we get lots of questions about*

[methane] *here lately*". When asked directly if they were aware of the claims that seaweed supplements could reduce methane emissions from cows, all eight interviewees said yes.

Other benefits

Other reasons for feeding seaweed that were mentioned by feed suppliers include reproduction, iodine supplementation, immune function, and hair coat deficiencies. One supplier noted that a lot of these issues go hand in hand, saying "*if I see an immune challenge on a herd- somatic cell, hoof health, hair coat challenges just- could be reproduction- I'll suggest maybe we could add that in as well to just help bring an immune booster to the herd*". Another supplier echoed this sentiment that feeding seaweed can have a multitude of health benefits: "*if I see an immune challenge on a herd-- somatic cell, hoof health, hair coat challenges, could be reproduction-- I'll suggest maybe we could add that in as well to just help bring an immune booster to the herd*".

Reasons why seaweed supplements are not currently used

Feed suppliers expressed many reasons that they believe some farmers don't currently use seaweed supplements. As discussed earlier, these reasons vary between organic and conventional farms, with perhaps more barriers to entry for conventional farmers. The primary barriers discussed by feed suppliers were price & cost effectiveness, volume needs at the mill, insufficient supply of seaweed, lack of investment from the industry, and alternatives on the market. In addition to these more structural barriers to increased use of seaweed supplements, feed suppliers expressed some knowledge gaps that they need to fill before they would feel comfortable recommending these products.

Logistical and Infrastructural Barriers to Use

Price & Cost-Effectiveness

The barrier to seaweed supplement use that was expressed most frequently was price and cost effectiveness. Nearly every supplier interviewed said that *"the largest barrier would be cost".* Unsurprisingly, suppliers spoke to inflation, noting that *"like everything, cost probably has about doubled in the last two or three years"* and supply chain issues are being a possible reason for this high price; *"it's tough to get and the price will reflect that".*

Suppliers shared that for the farmers that do use seaweed supplements, use fluctuates depending on how well their dairy operation is doing at any moment in time. One interviewee shared that "*even the most aspirational farmer is constrained by cost. Some years* [milk production] *can be very profitable. But in general, on the whole, it's not like these guys are just making an absolute killing all the time and can just spend their money willy nilly".* Even for farmers who can see past all the other barriers in question, price will still constrain them. One supplier added that *"when there's a squeeze on the dairy industry, it's one of the first things that gets cut from the ration".*

Of course, not all farmers are that invested in using seaweed products in the first place. To them, the price is an even bigger deterrent. Feed suppliers who work directly with farmers believe that *"farms are looking for the lowest cost with the highest production, and so if it's a little too high on cost, just from a demand point, it won't even be looked at because, honestly… this is me just being as honest as possible: the farmers really don't care".* This sentiment was shared by another supplier who said " [farmers] *care about the milk truck and the milk checks but not so much about the feed. As long as it gets the milk".* While this apathy does not reflect every dairy farmer in the Northeast U.S., it is a belief held by feed suppliers that conventional dairy farmers only care about getting the most milk for the lowest input cost.

However, other farmers can justify the added cost of feeding seaweed if they see an appropriate benefit; "*a dairy farmer is basically looking at cost all the time. And so, it has to be cost effective, has to actually work".* Nearly all interviewees expressed this need for cost-effectiveness in a product. One explained it this way: *"cost effectiveness implies both that it is effective and the price you're paying for whatever result it's yielding is reasonable".* The benefit that farmers need to see is something that either

helps them produce more milk, or "*it's gotta give them a competitive advantage"* because *"if they don't have a competitive advantage, they're gonna go for the lowest price".* Being certain on this cost-effectiveness helps suppliers do their job better too: "*from a sales standpoint, I need to know that my farmers are going to see the added value".*

Volume needs at the mill

Another concern that came up with feed suppliers is that often the mills they purchase from only work with large quantities of feed ingredients. In the case of introducing red seaweed for methane reduction, Kinley et al (2020) demonstrated reduction with just .2% of the total feed mix being seaweed. As one feed suppler said: "*we don't see a lot of adding small amounts of certain products. I'm going to pick algae, but assuming it would be more of a trace amount… we don't see that so much in this."* Due to truck sizes and trucking fees, mills generally only bring in full trucks to make the fees cost effective. Due to seaweed fluctuating in availability and requiring such a low quantity to reduce methane, feed suppliers feel that mills may have a hard time accommodating this. A supplier said that they *"wouldn't promote the product unless we had a lot of customers that want to use* [it]. *This specific mill is… commercial dairy feed but it's, but we're producing about 500 tons a day going out"* and another added that they *"only take in like 30 tons at a time at the minimum".* Figuring how to make the quantity of seaweed in a feed mix work for both seaweed suppliers and feed mills is seen as a barrier to getting it on the commercial market.

Insufficient supply

Among the three suppliers that regularly sell seaweed supplements, all of them expressed that harvests fluctuate from year to year and can cause shortages. These shortages were often talked about in relation to a price increase as well; *"sometimes there's all we need and other times it's very limited. It's tough to get and the price will reflect that".* Shortages on seaweed products directly impact the quantity used on a farm, as one supplier noted: *"it's a product that might get used on a limited basis from time to*

time. What I have noticed with kelp meal is that it sometimes it's kind of feast or famine". If the goal is to see consistent use of seaweed supplements to reduce methane emissions from cows, supply will need to be consistent enough to keep the price stable, otherwise it will be the first thing cut from feed mixes.

This instability in supply effects the feed suppliers we interviewed too, with farmers sometimes going to other suppliers for seaweed products and costing them business; *"do they buy it from us exclusively? It's really competitive, so they'll buy it wherever they can get it".* Even when they can keep a steady supply of seaweed, one interviewee said that *"supply is a challenge, so we end up with three different ones"*. One supplier mentioned supply shortages as being the main barrier they see to farmers using seaweed supplements; *"I mean if there's a barrier, it's because of our supply".* The same supplier commented on previous incidents of rationing the supplements, saying *"we've had to limit what farmers can take at a time because we have a limited supply and trying to make everybody have some"*.

One supplier who works with seaweed supplements frequently expressed that they haven't seen massive shortages yet, but that they are aware "*that industry wide, there isn't a whole lot of stored inventory".* They also commented on the COVID-19 pandemic causing disruptions to their supply and demand cycle; *"throughout the pandemic, demand was strong, supply was reasonable, and it's finally wiped out any buffer inventory that the industry had. And I'd expect the spring will be very—there will be a whole lot less kelp than people actually want to be putting into feeds".* Similarly, they spoke of previous shortages due to a major late season ice. In this case, the first summer after the ice event saw normal supply due to stored inventory, but the following summer saw massive shortages because the stored inventory was out. For season-to-season fluctuations to not impact present availability and price, the industry would need to invest in inventory storage.

Lack of investment from industry

An important factor that arose when talking to feed suppliers is that their job ultimately is to make sales. The same can be said for mills and other actors along the feed supply chain. When it comes to seaweed supplements, *"there's not enough money in it, and these businesses are run by money"* said one

supplier; *"money runs the world".* A few suppliers noted that they rarely, if ever, hear of a seaweed salesperson trying to market a product to them. One even expressed interested in hearing more, saying *"I'd like to know more about it, but… I get people knocking on my door all day long trying to sell this stuff, but there's nobody trying to sell me kelp"*. This sentiment was echoed by others who said, *"there's no kelp champion out there trying to penetrate the commercial market".* They believed this marketing would make a difference in farmers wanting to try these products; *"a direct representation is what's really critical for somebody to go to the producer and explain the benefits of the product".* There was a shared belief among the interviewees working in commercial dairy that unless someone became a spokesperson for seaweed and gave them a compelling reason to supply it, that they, as suppliers, wouldn't be quick to start offering it on their product line.

Alternatives on the market

The feed suppliers interviewed in this study generally expressed an interest in products that can reduce methane emissions from cows, but three alternatives to seaweed came up during interviews. While this didn't seem to be a major barrier to the current use of seaweed products, since current products aren't marketed as methane reducers, this could be a barrier going forward. Alternatives that were discussed include *"like a muzzle type thing on the front of the cow for breathing that would reduce burping"*, a feed additive under trial right now (that does not contain seaweed), and essential oils. The supplier who shared about the feed additive could not give further details because they are taking part in the trial. The supplier who spoke about the essential oils shared that there is skepticism about the effectiveness and some nutritionists recommend it while others do not.

What is needed to recommend use

In addition to the logistical and structural barriers discussed above, the feed suppliers interviewed all expressed that they need more information and evidence on seaweed supplements before they would

be willing to recommend them to farmers. The information they needed generally fell into two categories: scientific evidence and farms modeling applicability. This supplier summarized this well: *"I wanna see two things before we consider using your product or technology and the first is solid research. That's peer reviewed university research and the second is field applicability".* Other desired information came up with less frequency.

Scientific evidence

It was a widely shared belief among feed suppliers in this study that there is a lack of scientific evidence to back up the claims that seaweed supplements can reduce methane, on top of other known health benefits of seaweed products currently on the market. One supplier said, *"I think there is definitely a lot of interest from our customers in using products like these, but there is a lot of a lot of hyperbole in marketing and very little hard research to back up what the salespeople will tell you the products do".* While there are published scientific papers demonstrating the effectiveness of seaweed supplements on methane emissions, this information in not finding an audience in the feed supply sector. In speaking to potential benefits of seaweed supplements, one supplier even said, *"I've never seen anything where you did a Latin 4 by 4 or even a farm trial, where you have a control group and you have a kelp group and the kelp group makes more milk".* Suppliers commented on a lack of knowledge at the biochemical level as to what the benefits of seaweed supplements are, which makes it hard to sell to farmers.

Farms modeling applicability

What appeared even more consequential to these feed suppliers was the lack of farm-based evidence. Nearly all interviewees who do not currently supply seaweed products discussed the need to see trials done on farms, with real farmers, before they would feel comfortable marketing it. This is something they haven't seen yet: *"I haven't heard any mainstream evidence that… let's say a farm doing it and showing that there is a reduction* [in methane production] *or the benefits of it".* They want farms to

model the applicability of novel seaweed supplements before they recommend or sell them. This modeling can impact the industry folks, as one supplier said; *"As a whole, you'll find industry professionals -- because there's no research on it -- don't support things like this. It's like experience… use it and find out 'wow it does work, there is something to it.'".* Testing newer products on farms can also help stir up interest among other farmers. With this type of evidence, suppliers can go to farms and say, *"this farm that you know, that's in New York State, they've been using it for six months and this is what happened"* which this feed supplier described as *"the golden ticket for any product"*.

Other necessary knowledge

There were a few other bits of information that feed suppliers noted as necessary to recommend a seaweed supplement. One was a demonstrated demanded from farms: *"I wouldn't promote it unless it was something that the salespeople came back to me and said the farmers are demanding it. It almost-- it has to come from the farmers demanding it and saying if you don't put this in, we're gonna go somewhere else".* Suppliers also noted that they would consider supplying it if this demand came from their nutritionists. Secondly, a supplier brought up needed to know a return on investment (ROI) value for adding a supplement like this. Dollar values are incredibly important when deciding to add a supplement into a feed mix on a dairy farm. One supplier put it this way: *"if I had a clearer picture on benefits and ROI and those sorts of things. I potentially could still recommend it, even if it's $75 a bag but gets justified to get a three to one return. I have no problem recommending that if I know those are solid numbers"*.

Supply chain

We asked the feed suppliers who supply seaweed supplements to track the supply chain as far back as they could. Generally, this was a two-step process; the feed supplier bought it from a processor or distributor, who source bought it from the harvesters. Feed suppliers had more details on who they

directly purchased from, although sometimes they did not even know the name of the processor or distributor. One supplier who works heavily with seaweed products and purchased seaweed directly from the grower in Iceland.

Direct supply chain

The feed suppliers had a few takeaways regarding the direct source of their seaweed supplements. The first is that they can get it from multiple places, and there is not one sole distributor. One supplier said, *"We can buy it from any number of suppliers, but we currently buy it through* [one]*".* Another expressed having three different suppliers and attributed this to supply shortages, saying "*supply is a challenge, so we end up with three different ones".*

The second takeaway about the direct supply was that the seaweed products mostly seemed to be coming from the Northeast United States or Canada. Two suppliers mentioned where they purchased seaweed from by name, and another knew it came from French Canada but were unsure exactly where from. One of the suppliers who bought from an American company purchased directly from them, saying *"I mean they harvest it, they mechanically dry it, and then it's packaged in 50 pound bags and put on a truck right to us".*

The last major takeaway about the direct seaweed supply chain was that feed suppliers tend to buy seaweed products from resellers. One supplier expressed that this is not the case for all feed supplements, but it is for seaweed, saying *"a lot of things that we purchase, we purchased direct from supply from the source, but in the case of something like this, we buy it through a reseller".* Two other suppliers mentioned buying it from resellers. One of the conventional suppliers, who doesn't sell seaweed often, says "*we are a conventional supplier, and we work with in conjunction within organic supplier. So, we were sourcing it through an organic supplier",* demonstrating that organic feed suppliers may play this role of reseller for conventional suppliers.

Upstream supply chain

The main takeaway that the feed suppliers shared regarding upstream supply chain is that they don't know a lot. When asked where their reseller gets the seaweed, one suppler said *"I'm not directly aware of how… where they source, how the harvest takes place, and then the whole manufacturing process"*. Generally, the interviewees believed that their suppliers purchased seaweed directly from the manufacturer or harvester; *"we buy it from a reseller who buys it from the source, I'm guessing".* While it may be too soon to map out an exact step by step supply chain of the entire seaweed harvest to cow feed line, some feed suppliers shed light on their experiences buying seaweed. This process often involved a middleman between the harvester and the feed supplier themselves, but not always.

Outlook

Feed suppliers had some ideas about how seaweed supplements to reduce methane emissions in dairy would fit into their industry. For the most part, feed suppliers were interested in seaweed supplements, either for their health benefits or the potential to replace manmade mineral supplements that may have harmful contaminants; *"I like the idea behind the kelp or seaweed. It's natural, right? It's a natural product".* Many also expressed interest in the future of red seaweed (*Asparagopsis taxiformis*) supplements that could reduce methane emissions. A few shared frustrations with the notion that farmers wouldn't be interested in the sustainability side, saying *"I think everybody kind of lumps farmers into 'they're super conservative, stuck in their ways', but these big dairies, these are big companies that would go out of business if they weren't progressive and willing to try new things"*. Another supplier said *"I feel like the general sentiment or general preconception is that farmers wouldn't be interested in this. But I think they are. A lot of our customers now have the methane digesters,"* suggesting that farmers have already invested in similar sustainable farm practices.

While almost all of the suppliers interviewed were interested in the potential of methane reducing seaweed supplements, some shared a fear of overharvesting if the product becomes popular. One supplier

touched on this by saying *"I guess my fear is what is the long-term impact? If it does show a methane reduction, there's gonna be a big push to harvest a lot of this. And then what's the long term, environmental, ecological, climate impacts of grabbing all of this out of the ocean?".* Another supplier believes that this type of red seaweed cannot be sustainably harvested at the rates required to make a difference in methane outputs from dairy.

DISCUSSION

This qualitative study found that dairy feed suppliers are generally interested in ways to reduce methane emission in the dairy industry but see cost as a major limitation to implementation for farmers. Similar opinions were held by dairy farmers in the northeast U.S. (Tynan et al., 2023) and in the Netherlands (De Lauwere et al., 2015). de Lauwere at al (2015) found that farmers need more information before implementing novel sustainability measures on the farm; our study aligned with this, showing that feed suppliers need more information and examples of farmers using seaweed feed supplements before they'd be willing to recommend them to customers. Much like Norwegian sheep farmers (Bay-Larsen et al., 2018), the dairy feed suppliers we interviewed expressed that they are aware of the health benefits of feeding seaweed. These benefits were generally better known among the organic dairy field, as compared to conventional, which aligns with findings from Tynan at al (2023).

One barrier to recommending seaweed that was discussed by feed suppliers was the lack of sufficient scientific studies. There are published, peer reviewed studies on the topic (Black et al., 2021; Kinley et al., 2020; Machado et al., 2014; Min et al., 2021; Molina-Alcaide et al., 2017; Stefenoni et al., 2021), yet this information is either not sufficient for feed suppliers or is not being distributed to them. Dairy feed suppliers in this study brought up other barriers not previously mentioned in other studies including volume challenges at mills, the lack of investment into seaweed feed supplements from industry, and alternatives on the market. It is not surprising that these barriers arose for people who work in the feed supply chain but may not have come to mind for dairy farmers themselves.

The findings of this study demonstrate the need to gather insight from stakeholders along the entire supply chain from seaweed harvesters to dairy farmers, as their perspectives are valuable when assessing the feasibility of feeding seaweed to cows at scale. The findings also reveal the opportunities and barriers for feeding seaweed, from the perspective of feed suppliers. Researchers can use these when conducting further studies on willingness to pay for seaweed supplements, policy incentives, and more. Further, these findings highlight what feed suppliers need to know in order to back a new supplement; scientific knowledge, on-farm modeling, and nutritionist support. Advocates for the use of seaweed supplements should focus on getting this critical middleman the knowledge they need to feel confident recommending seaweed feed supplements in the future.

CONCLUSION

While research around seaweed feed supplements and their potential to reduce methane emissions from cows is growing, little research has been done to date regarding the opinions of niche supply chain actors such as dairy feed suppliers. Opinions of these critical stakeholders is important for understanding if these supplements are feasible, and what a supply chain for them may look like. Our findings show that diary feed suppliers in the northeast United States are open to the idea of methane reduction tools, and generally see the health benefits of seaweed supplements. However, they see price and cost-effectiveness as major barriers. They also see logistical barriers due to mill volume capacities, and industry barriers such as the lack of a "seaweed champion" working to sell these supplements. They broadly wish to see more scientific evidence and increased examples of farmers using seaweed supplements in the real world. This type of evidence could make them more comfortable recommending seaweed feed supplements to their buyers.

The preliminary findings shown here can serve as a foundation for further exploration into the opinions and preferences of dairy industry stakeholders regarding seaweed feed supplements. Our in-depth interviews with participants allowed for nuanced discussion regarding opinions of seaweed feed

supplements. Further studies could include gathering data from a wider data pool, and narrowing the type of information that is collected. Combining our nuanced individual responses with broader, survey-type responses would help provide a more complete picture of feed supplier opinions of seaweed. Additional research could also investigate what solutions dairy feed suppliers see to the barriers presented here.

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