Dietary Chemical Components and Enteric Methane Production

Subjects: Agriculture, Dairy & Animal Science

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Methanogenesis is critical in cattle because it prevents accumulation of metabolic hydrogen in the rumen by serving as a reducing equivalent sink. Alternative hydrogen sinks exist, however, and these alternative sinks are affected by the ingredient and chemical composition of the diet, such that the quantity of CH_4 produced by cattle varies based on dietary constituents that are fed. Diets that produce acetate liberate hydrogen to be used by methanogenic archaea to produce CH_4. Conversely, propionate serves as a net hydrogen sink, and diets that increase propionate and decrease acetate result in decreased ruminal CH_4 production, reflecting decreased availability of metabolic hydrogen for methanogens to reduce CO_2 to CH_4.

cattle diet formulation dietary chemical components

1. Introduction

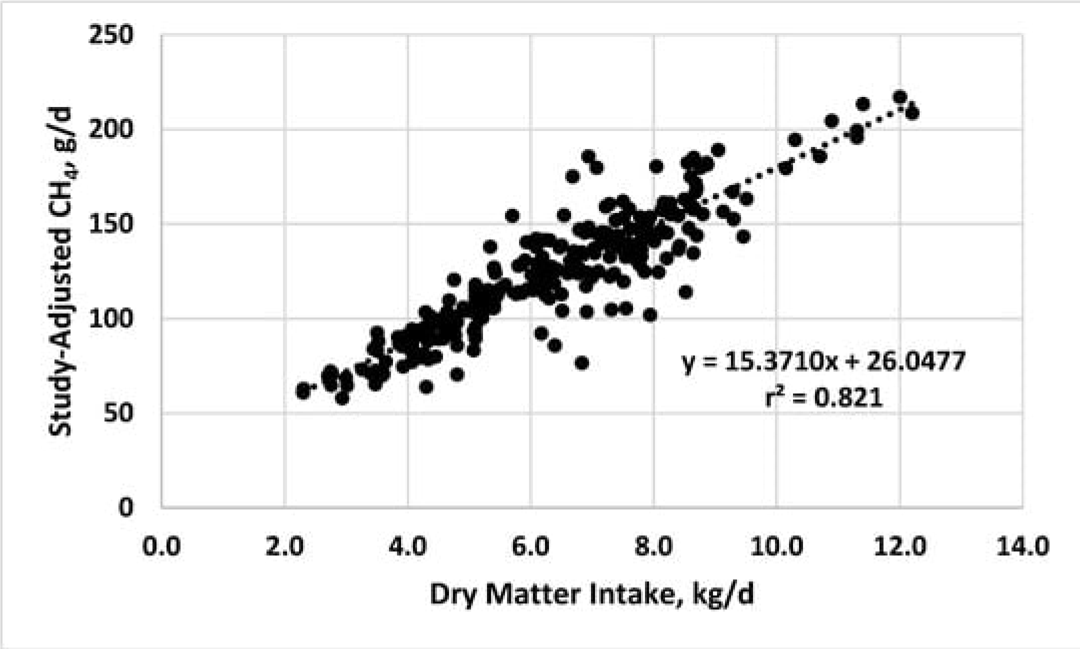
Beef cattle production is the single largest agricultural commodity area in the United States, contributing over USD 66 billion in receipts in 2019 [1]. Although cattle can convert low-quality feeds into high-quality protein for human consumption, they are a source of agricultural greenhouse gas emissions to the atmosphere. The agriculture sector in the United States contributes approximately 10% of total greenhouse gas emissions, and livestock contributes 3.8% [2]. Nonetheless, enteric CH_4 emissions are responsible for 30% of the anthropogenic methane budget, highlighting the need for a clear understanding of factors that affect CH_4 production and development of practical mitigation strategies.

Methanogenesis is critical in cattle because it prevents accumulation of metabolic hydrogen in the rumen by serving as a reducing equivalent sink [3]. Alternative hydrogen sinks exist, however, and these alternative sinks are affected by the ingredient and chemical composition of the diet, such that the quantity of CH_4 produced by cattle varies based on dietary constituents that are fed. Diets that produce acetate liberate hydrogen to be used by methanogenic archaea to produce CH_4. Conversely, propionate serves as a net hydrogen sink, and diets that increase propionate and decrease acetate result in decreased ruminal CH_4 production, reflecting decreased availability of metabolic hydrogen for methanogens to reduce CO_2 to CH_4.

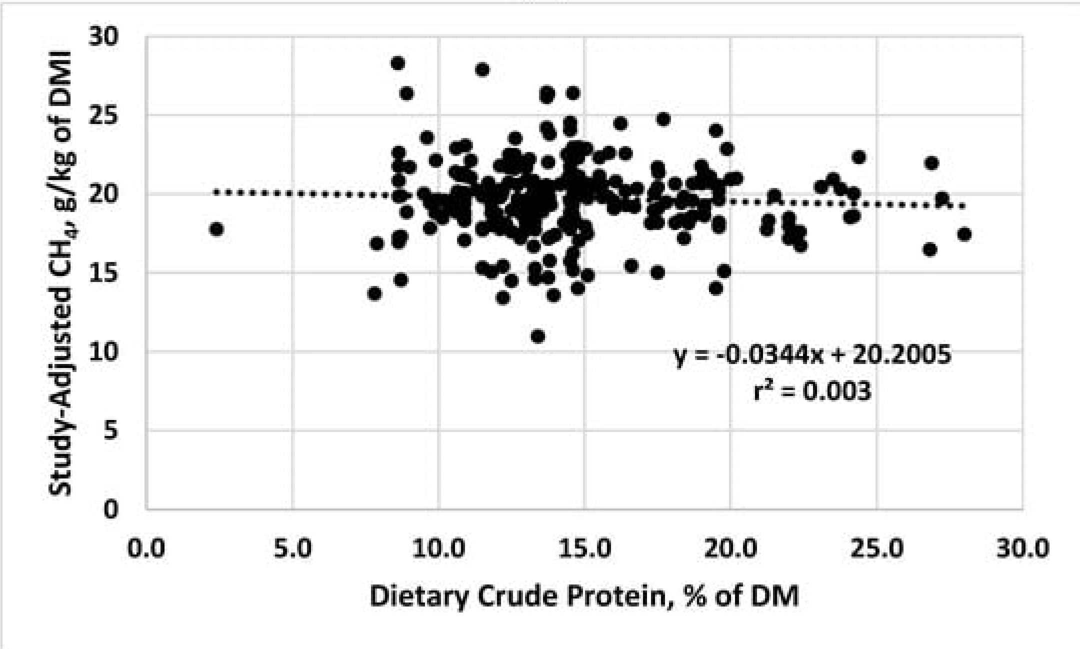
2. Dietary Chemical Components and Enteric Methane Production

2.1. Relationships of Methane Production to Dry Matter Intake and Dietary Chemical Components

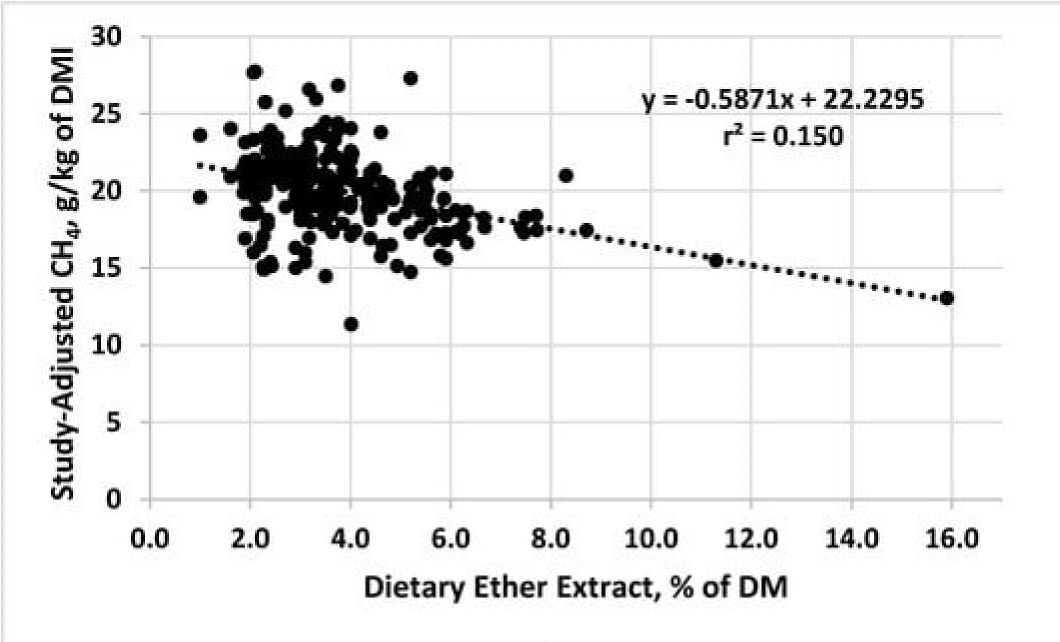
Results of the mixed model regression analyses are shown in **Table 1**, with graphical representations of the relationships shown in **Figure 1**. Because of the importance of DMI as a driver of enteric CH_4 production, initial analyses involved regression of daily CH_4 production on DMI. As expected, the relationship between these two variables was strong, with DMI accounting for 82.1% of the variation in daily CH_4 production (**Table 1**; **Figure 1**). Dry matter intake has consistently been identified as a key component of equations to predict CH_4 production in cattle [4][5][6][7], with DMI alone often yielding prediction equations that are equivalent in accuracy and precision to more complex equations.


Study-Adjusted CH_4, g/d
250
200
150
100
50
0
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
Dry Matter Intake, kg/d
y = 15.3710x + 26.0477
r² = 0.821

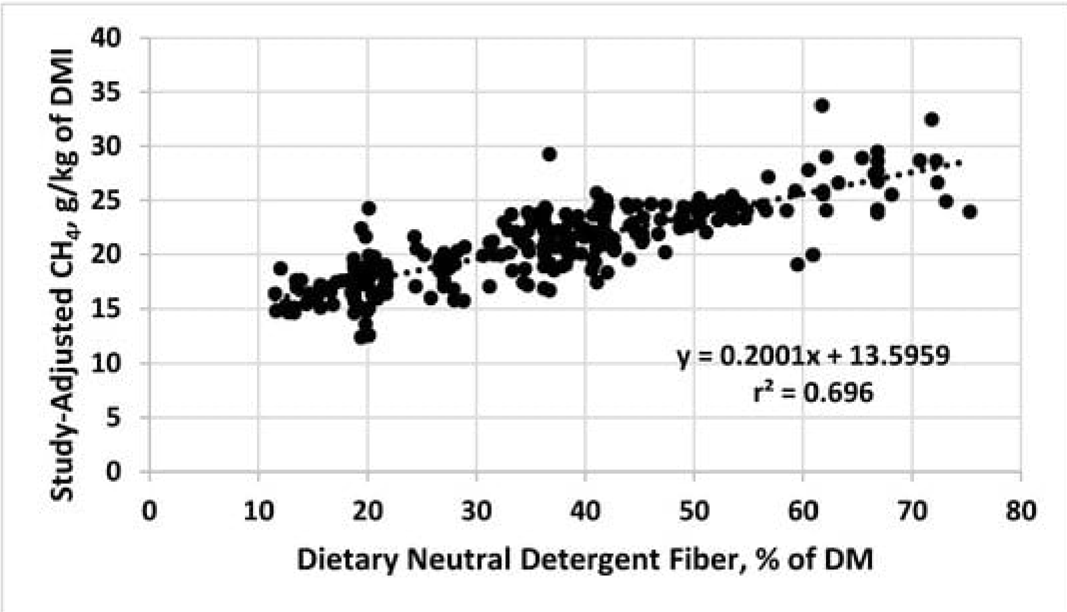
(A)


Study-Adjusted CH_4, g/kg of DMI
30
25
20
15
10
5
0
0.0
5.0
10.0
15.0
20.0
25.0
30.0
Dietary Crude Protein, % of DM
y = -0.0344x + 20.2005
r² = 0.003

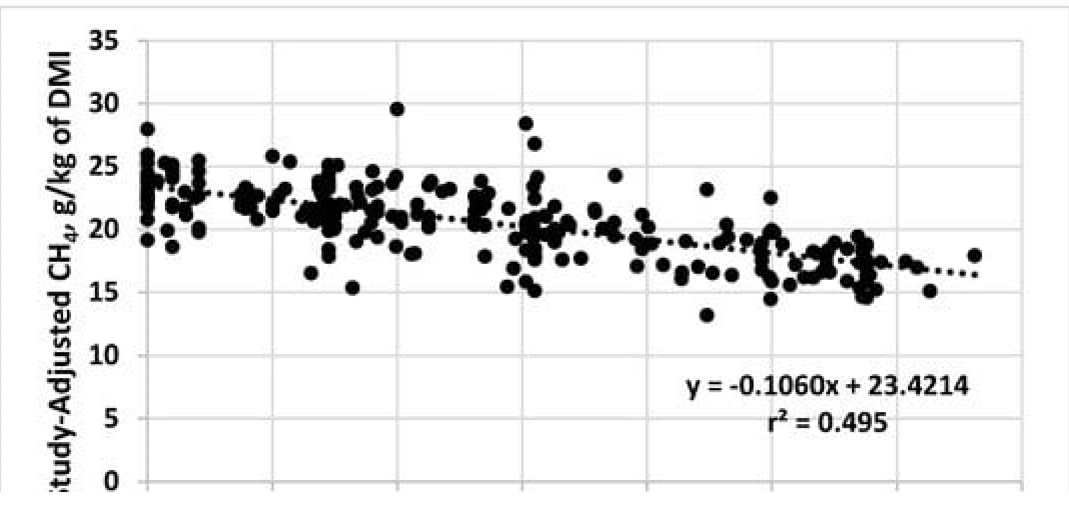
(B)

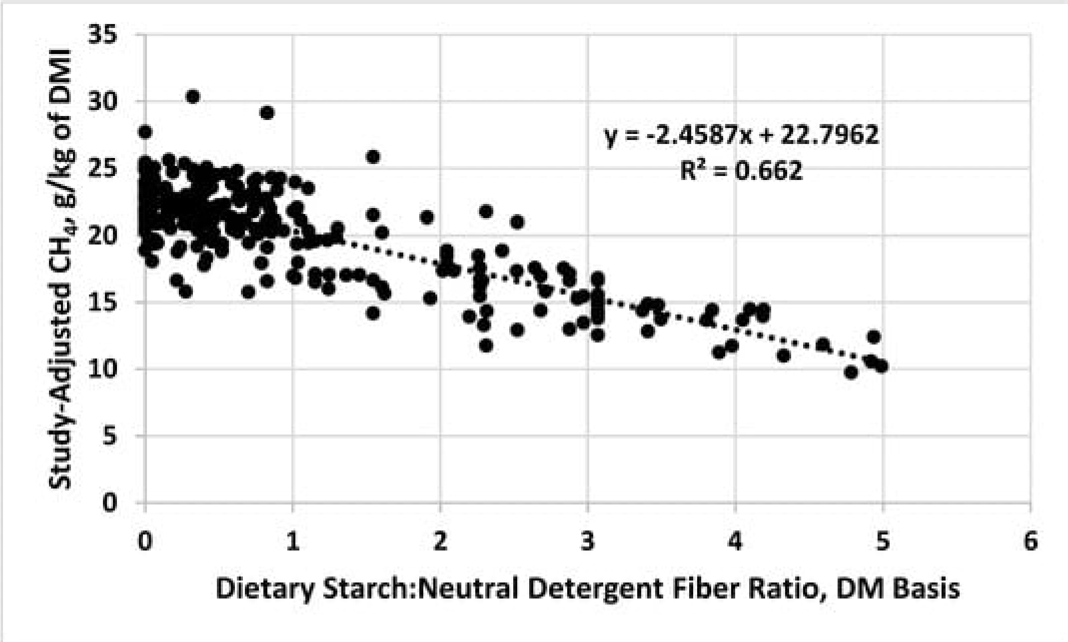

Study-Adjusted CH_4, g/kg of DMI
Dietary Ether Extract, % of DM
y = -0.5871x + 22.2295
r^2 = 0.150
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
0
5
10
15
20
25
30

(C)

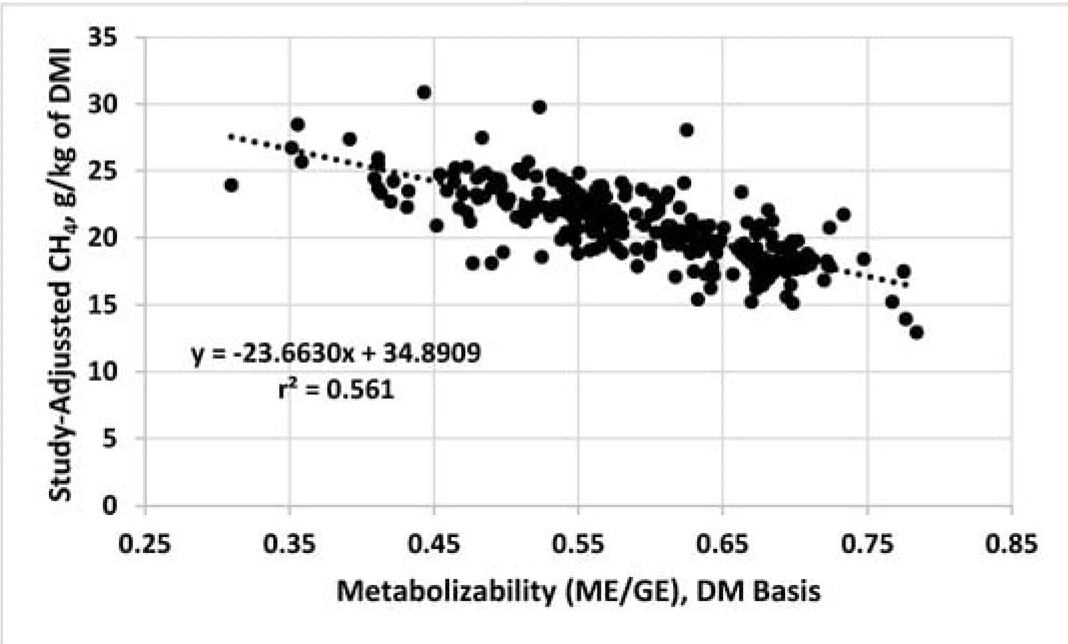

Study-Adjusted CH_4, g/kg of DMI
Dietary Neutral Detergent Fiber, % of DM
y = 0.2001x + 13.5959
r^2 = 0.696
0
10
20
30
40
50
60
70
80
0
5
10
15
20
25
30
35
40

(D)


y = -0.1060x + 23.4214
r^2 = 0.495
0
5
10
15
20
25
30
35



(F)



(G)

Figure 1. Relationships between study-adjusted enteric methane production (g/d or g/kg of dry matter intake) and dry matter intake DMI; (**A**), dietary crude protein (**B**), ether extract (**C**), neutral detergent fiber (**D**), starch (**E**), starch:neutral detergent fiber ratio (**F**), and diet metabolizability (metabolizable energy/gross energy; (**G**) developed from a literature database.

Table 1. Relationships between study-adjusted enteric methane production (g/d) and dry matter intake (DMI) and methane production expressed as g/kg of DMI and various dietary chemical components and diet metabolizability developed from a literature database [1].

Item [2]	Regression Coefficients		Regression Statistics	
	Intercept	Slope	RMSE	r^2
	---- CH_4, g/d ----			
Dry matter intake, kg/d	26.0477	15.3710	13.96	0.821
p-values [3]	<0.001	<0.001	CV = 11.39%	
Lower 95% CI	20.2892	14.4950		
Upper 95% CI	31.8062	16.2470		
	---- CH_4, g/kg of DMI ----			
Crude protein, %	20.2005	−0.0344	2.53	0.003
p-values [3]	<0.001	0.381	CV = 12.82%	
Lower 95% CI	19.0317	−0.1115		
Upper 95% CI	21.3694	0.0428		
Ether extract, %	22.2295	−0.5871	2.31	0.150
p-values [3]	<0.001	<0.001	CV = 11.57	
Lower 95% CI	21.5201	−0.7577		
Upper 95% CI	22.9390	−0.4165		
Neutral detergent fiber, %	13.5959	0.2001	2.02	0.696
p-values [3]	<0.001	<0.001	CV = 9.65	
Lower 95% CI	12.9563	0.1840		
Upper 95% CI	14.2355	0.2162		
Starch, %	23.4214	−0.1060	2.04	0.495
p-values [3]	<0.001	<0.001	CV = 9.89	
Lower 95% CI	22.9950	−0.1191		
Upper 95% CI	23.8478	−0.0929		
Starch:neutral detergent fiber ratio	22.7962	−2.4587	2.18	0.662
p-values [3]	<0.001	<0.001	CV = 10.91	
Lower 95% CI	22.4363	−2.6730		

Item [2]	Regression Coefficients Intercept	Regression Coefficients Slope	Regression Statistics RMSE	Regression Statistics r^2
Upper 95% CI	23.1561	−2.2444		
Metabolizability	34.8909	−23.6630	1.84	0.561
p-values [3]	<0.001	<0.001	CV = 8.80	
Lower 95% CI	33.3687	−26.2140		
Upper 95% CI	36.4131	−21.1120		

[1] Data were adjusted for random intercepts and slopes associated with the 63 studies in the database. [2] Dietary chemical composition data were expressed on a dry matter basis. Metabolizability = metabolizable energy divided by gross energy. [3] Probability that the intercept and slopes differ from zero; CV = RMSE divided by the overall mean of dry matter intake, dietary chemical components, and metabolizability, expressed as a percent; r^2 is not adjusted for the number of parameters in the model.

2.2. Managing Methane through Feeding Intake Management Strategies

Energy requirements of ruminant livestock are sufficiently well defined to allow "programming" of DMI to meet the needs for a given level of production. Because of the importance of DMI as a driver of enteric CH_4 production, the use of restricted feeding to limit over consumption or programmed feeding to achieve a particular rate of body weight gain for feedlot beef cattle might offer a potential avenue for the feedlot industry to decrease CH_4 production [8]. In addition to decreasing enteric CH_4, feeding management approaches that decrease DMI would be expected to decrease fecal output, thereby also decreasing CH_4 losses via manure [8]. Moreover, effects of decreasing DMI through feeding management should be additive with other CH_4 mitigation approaches such as feed additives that inhibit methanogenesis. Nonetheless, for feedlot cattle, decreasing DMI also carries a risk of extending the days on feed to reach a particular carcass weight and composition endpoint or negatively affecting meat quality indices like marbling. Such increases in the length of the feeding period could negatively affect the economics of production and potentially negate decreases in enteric and manure CH_4 production associated with management of feed intake, requiring careful evaluation of this approach as a CH_4 mitigation strategy. An alternative to managing DMI as a mitigation strategy would be the selection of more efficient animals (e.g., cattle with low residual feed intake) [9].

Opportunities to modify CH_4 through management of DMI in lactating dairy cattle are likely more limited than for feedlot cattle. Feeding higher concentrate diets could decrease CH_4 production in lactating dairy cows, both through altered ruminal fermentation shifting metabolic hydrogen away from CH_4 and through decreased DMI needed to maintain desired production levels. Nonetheless, decreasing the level of NDF from roughage to allow for lower DMI would likely have a negative effect on milk quality, specifically milk fat content and would possibly have negative effects on animal health through an increased risk of acidosis, rumenitis, and systemic inflammation [9][10][11]. Thus, although management of DMI to lower CH_4 production offers possibilities in lactating dairy cows, it would

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Sinks: 1990–2016; U.S. Environmental Protection Agency: Durham, NC, USA, 2018. Available online: https://www.epa.gov/sites/production/files/2018-01/documents/2018_complete_report.pdf (accessed on 15 March 2022).

3. McAllister, T.A.; Newbold, C.J. Redirecting rumen fermentation to reduce methanogenesis. Aust. J. Exp. Agric. 2008, 48, 7–13.
4. Ellis, J.L.; Kebreab, E.; Odongo, N.E.; McBride, B.W.; Okine, E.K.; France, J. Prediction of methane production from dairy and beef cattle. J. Dairy Sci. 2007, 90, 3456–3467.
5. van Lingen, H.J.; Niu, M.; Kebreab, E.; Valadares Filho, S.C.; Rooke, J.A.; Duthie, C.-A.; Schwarm, A.; Kreuzer, M.; Hynd, P.I.; Caetano, M.; et al. Prediction of enteric methane production, yield and intensity of beef cattle using an intercontinental database. Agric. Ecosyst. Environ. 2019, 283, 106575.
6. Ribeiro, R.S.; Rodrigues, J.P.P.; Maurício, R.M.; Borges, A.L.C.C.; Reis e Silva, R.; Berchielli, T.T.; Valadares Filho, S.C.; Machado, F.S.; Campos, M.M.; Ferreira, A.L.; et al. Predicting enteric methane production from cattle in the tropics. Animal 2020, 14, s438–s452.
7. Marumo, J.L.; Laierre, P.A.; Van Amburgh, M.E. Enteric methane emissions prediction in dairy cattle and effects of monensin on methane emissions: A meta-analysis. Animals 2023, 13, 1392.
8. Galyean, M.L.; Hales, K.E. Feeding management strategies to mitigate methane and improve production efficiency of feedlot cattle. Animals 2023, 13, 758.
9. Beauchemin, K.A.; Ungerfeld, E.M.; Eckard, R.J.; Wang, M. Review: Fifty years of research on rumen methanogenesis: Lessons learned and future challenges for mitigation. Animal 2020, 14, s2–s16.
10. Haque, M.N. Dietary manipulation: A sustainable way to mitigate methane emissions from ruminants. J. Anim. Sci. Technol. 2018, 60, 15.
11. Krogstad, K.C.; Bradford, B.J. Does feeding starch contribute to the risk of systemic inflammation in dairy cattle? JDS Comm. 2023, 4, 14–18.
12. Eugene, M.; Klumpp, K.; Sauvant, D. Methane mitigating options with forages fed to ruminants. Grass Forage Sci. 2021, 76, 196–204.

need to be combined with other dietary formulation and feed additive strategies for successful application in practice.

2.3. Applications to Diet Formulation for Mitigation of Methane Emissions

Based on the results of the regression analyses described previously, the key dietary factors to consider in formulation strategies to decrease enteric CH_4 production would be concentrations of NDF, starch, and diet metabolizability, with dietary EE concentration being of lesser importance and dietary CP concentration having virtually no effect. Practically, these key factors are often interrelated in terms of diet formulation. Mixed diets with decreased NDF concentration often have increased starch concentration (i.e., a decreased forage and increased grain), which also results in an increased ME concentration and thereby increased metabolizability. For confined cattle fed mixed diets, changing the forage:concentrate ratio is widely recognized as a feasible CH_4 mitigation strategy [9].

With all-forage diets for example, a variety of factors affect NDF concentration, including forage type and maturity. More digestible forages decreased CH_4 yield in dairy cattle and sheep, but effects were less clear for beef cattle [12]. Nonetheless, increased forage quality generally decreases CH_4 production per unit of animal product because DMI and animal production typically increase as forage quality increases [9]. Increased digestibility of higher-quality forages also would be expected to decrease manure CH_4 losses. Type of forage can be important, as greater CH_4 yield was reported for C4 vs. C3 grasses and warm-season legumes [13].

As noted previously, feeding diets with a greater concentration of starch is a repeatable approach to decrease CH_4 yield and should also decrease CH_4 associated with manure. Starch generally decreases enteric CH_4 because methanogens are sensitive to low ruminal pH [14] and feeding starch results in a lower ruminal pH than feeding all-forage diets [15]. Even so, Beauchemin et al. [9] observed that the global capacity to increase grain feeding to ruminants is limited, so using increased dietary starch as a mitigation tool is limited to production systems in which grains are normally fed at high levels. Grain type (e.g., horny vs. floury endosperm) also can affect starch digestion [16], with lesser starch digestion with a greater proportion of horny endosperm, although steam flaking can offset the negative effects of endosperm type [16]. Heat and moisture processing methods like steam flaking increase gelatinization of starch and increase the ruminal proportion of propionate and decrease ruminal pH, thereby decreasing CH_4 yield [16][17].

Although adding dietary fat sources has been extensively studied as a tool for decreasing CH_4 yield [9], and the regression analyses showed a negative relationship between dietary EE concentration and CH_4 yield, the relationship was highly variable and of low predictive value. With potential negative effects of fat on fiber digestion noted previously, as well as relatively high cost of fat sources, careful consideration should be given to the total concentration of fat in the diet, as well as to the sources of fat added to the diet.

It should be noted that for practical implementation of any dietary formulation approach to mitigate CH_4 yield, feed mixing and delivery, as well as potential sorting of feed by animals are issues of concern. If diets are inadequately

13. Archimède, H.; Eugène, M.; Marie Magdeleine, C.; Boval, M.; Martin, C.; Morgavi, D.P.; Lecomtec, P.; Doreau, M. Comparison of methane production between C3 and C4 grasses and legumes. Anim. Feed Sci. Technol. 2011, 166–167, 59–64.
14. Van Kessel, J.A.S.; Russell, J.B. The effect of pH on ruminal methanogens. FEMS Microbiol. Ecol. 1996, 20, 205–210.
15. Beauchemin, K.A.; Kreuzer, M.; O'Mara, F.; McAllister, T.A. Nutritional management for enteric methane abatement: A review. Aust. J. Exp. Agric. 2008, 48, 21–27.
16. Corona, L.; Owens, F.N.; Zinn, R.A. Impact of corn vitreousness and processing on site and extent of digestion by feedlot cattle. J. Anim. Sci. 2006, 84, 3020–3031.
17. Hales, K.E.; Cole, N.A.; McDonald, J.C. Effects of corn processing method and dietary inclusion of wet distillers grains with solubles on energy metabolism, carbon-nitrogen balance, and methane emissions of cattle. J. Anim. Sci. 2012, 90, 3174–3185.

mixed, thereby resulting in the consumption of feed with variable concentrations of particular nutrients, benefits of dietary mitigation strategies would be decreased. Similarly, diets or feeding practices that promote sorting of feed ingredients by groups of cattle could negate the effects of dietary management strategies.