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Direct and indirect predictions of enteric methane daily production, yield, and intensity per unit of milk and cheese, from fatty acids and milk Fourier-transform infrared spectra

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ABSTRACT

Mitigating the dairy chain's contribution to climate change requires cheap, rapid methods of predicting enteric CH_4 emissions (EME) of dairy cows in the field. Such methods may also be useful for genetically improving cows to reduce EME. Our objective was to evaluate different procedures for predicting EME traits from infrared spectra of milk samples taken at routine milk recording of cows. As a reference method, we used EME traits estimated from published equations developed from a meta-analysis of data from respiration chambers through analysis of various fatty acids in milk fat by gas chromatography (FA_{GC}). We analyzed individual milk samples of 1,150 Brown Swiss cows from 85 farms operating different dairy systems (from very traditional to modern), and obtained the cheese yields of individual model cheeses from these samples. We also obtained Fourier-transform infrared absorbance spectra on 1,060 wavelengths (5,000 to 930 waves/cm) from the same samples. Five reference enteric CH_4 traits were calculated: CH_4 yield (CH_4/DMI, g/kg) per unit of dry matter intake (DMI), and CH_4 intensity (CH_4/CM, g/kg) per unit of corrected milk (CM) from the FA_{GC} profiles; CH_4 intensity per unit of fresh cheese (CH_4/CY_{CURD}, g/kg) and cheese solids (CH_4/CY_{SOLIDS}, g/kg) from individual cheese yields (CY); and daily CH_4 production (dCH_4, g/d). Direct infrared (IR) calibrations were obtained by BayesB modeling; the determination coefficients of cross-validation varied from 0.36 for dCH_4 to 0.57 for CH_4/CM, and were similar to the coefficient of determination values of the equations based on FA_{GC} used as the reference method (0.47 for CH_4/DMI and 0.54 for CH_4/CM). The models allowed us to select the most informative wavelengths for each EME trait and to infer the milk chemical features underlying the predictions. Aside from the 5 direct infrared prediction calibrations, we tested another 8 indirect prediction models. Using IR-predicted informative fatty acids (FA_{IR}) instead of FA_{GC}, we were able to obtain indirect predictions with about the same precision (correlation with reference values) as direct IR predictions of CH_4/DMI (0.78 vs. 0.76, respectively) and CH_4/CM (0.82 vs. 0.83). The indirect EME predictions based on IR-predicted CY were less precise than the direct IR predictions of both CH_4/CY_{CURD} (0.67 vs. 0.81) and CH_4/CY_{SOLIDS} (0.62 vs. 0.78). Four indirect dCH_4 predictions were obtained by multiplying the measured or IR-predicted daily CM production by the direct or indirect CH_4/CM. Combining recorded daily CM and predicted CH_4/CM greatly increased precision over direct dCH_4 predictions (0.96–0.96 vs. 0.68). The estimates obtained from the majority of direct and indirect IR-based prediction models exhibited herd and individual cow variability and effects of the main sources of variation (dairy system, parity, days in milk) similar to the reference data. Some rapid, cheap, direct and indirect IR prediction models appear to be useful for monitoring EME in the field and possibly for genetic/genomic selection, but future studies directly measuring CH_4 with different breeds and dairy systems are needed to validate our findings.

Key words: mid-infrared, near-infrared, ecological footprint, greenhouse gas, global warming

INTRODUCTION

Simple, noninvasive, cheap methods are needed that may be used with individual dairy cows at the population level to monitor herds for enteric CH_4 emissions (**EME**) and possibly to reduce them through genetic improvement of dairy cattle. Some studies have shown that the phenotypic variability of EME has a genetic basis (Pryce and Bell, 2017), but a major problem in genetically evaluating animals lies in the fact that the gold standard for accurate, precise EME quantification (i.e., the respiration chamber) is an expensive tool that can be used only in an artificial environment and on few animals, which is a problem in a genetic approach,

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and is available only in some research centers (de Haas et al., 2017).

Simpler, direct methods involve taking samples of the air near the cows' nostrils and mouths, and from these estimating the CH_4 eructated from the rumen and, in part, that emitted from the intestine through the lungs, which represents about 6 to 14% of total EME (Immig, 1996). Theoretically more precise and accurate methods involve the continuous release of a gas tracer in the rumen at a known rate, which is used as a reference for calculating CH_4 emission (Beauchemin et al., 2012), often using instruments mounted on the back of the cows. These methods are, in any case, expensive and involve ethical/animal welfare issues. The most practical methods, easy to use at the farm level, involve placing sampling instruments in the automatic milking systems or the automatic concentrate feeders (de Haas et al., 2017). These methods can sample the air at every visit of the cow (i.e., several times per day), but it is not clear to what extent the CH_4 emitted during milking or feeding is representative of the complete daily balance. Lastly, detectors that can function at a distance (laser, infrared) can be used during different phases of the cows' daily routine, but technicians are needed to operate them (Chagunda and Yan, 2011). The methods that do not use rumen tracers rely on measurement of the ratio between CH_4 and CO_2 in the air sample to predict daily CH_4 release on the basis of theoretical CO_2 emission predicted from one or more cow's traits (BW, milk yield, DMI, and so on; Madsen et al., 2010). These methods are less accurate and precise than respiration chambers, as the various EME patterns according to diet differ from the gold standard (Hammond et al., 2016) and from each other (Hristov et al., 2016), so their use is controversial (Wu et al., 2018).

Among the indirect methods based on genetic correlations with other traits, the favorable relation between EME and feed efficiency is very interesting (Basarab et al., 2013). However, the problem here is how to measure the feed DMI of individual animals at the population level. Interest is also growing in other indirect predictions of EME traits, as reviewed by Negussie et al. (2017). Among the more promising methods, studies have shown that the fatty acid (**FA**) profile of milk reflects microbial activity in the rumen, and therefore, EME, as reviewed by van Gastelen and Dijkstra (2016). Here, too, the gold standard for FA analysis [i.e., gas chromatography ($\mathbf{FA_{GC}}$)], despite being much simpler and cheaper than EME analyzed by respiration chambers, cannot be easily used in the context of routine milk recording schemes.

Infrared (**IR**) spectrometry has been widely used for predicting FA ($\mathbf{FA_{IR}}$) in milk (Rutten et al., 2009; Soyeurt et al., 2011; Ferrand-Calmels et al., 2014) and meat (Cecchinato et al., 2012), with interesting results. However, the major limitation is that, despite improvements in prediction methods (Eskildsen et al., 2014; Fleming et al., 2017), IR spectrometry yields good results for those milk FA with the highest concentrations, whereas some of the most interesting FA for predicting EME are those derived from microbial activity in the rumen, which are found in low concentrations (van Gastelen and Dijkstra, 2016). An alternative is to use IR spectrometry for direct prediction of EME traits from milk spectra, which is the most attractive option as IR spectra are routinely obtained from almost all individual milk samples processed within milk recording schemes and from bulk farm samples taken for milk quality pricing systems. In a preliminary study carried out on a very small number of cows, Dehareng et al. (2012) obtained promising results using Fourier-transform infrared (**FTIR**) spectra to predict the daily CH_4 production ($\mathbf{dCH_4}$, g/d) of individual cows, and CH_4 intensity (CH_4/CM, g/kg) expressed per unit of fat- and protein-corrected milk (**CM**) produced. Later, the same research group published promising results from a study of a larger number of cows (Vanlierde et al., 2015, 2016; Vanrobays et al., 2016), although Shetty et al. (2017), using similar approaches, obtained unsatisfactory results.

As various EME traits have been analyzed in different studies (van Gastelen and Dijkstra, 2016; de Haas et al., 2017), but have not been compared in large surveys, in a recent study we used the method of van Lingen et al. (2014) based on selected FA_{GC} to estimate CH_4/CM and CH_4 yield per unit of DMI (CH_4/DMI), and to study the effect of dairy system, herd within dairy system, and parity and lactation stage of dairy cows (Bittante et al., 2018). In addition, we calculated dCH_4 by multiplying daily CM yield (**dCMY**, kg/d) by CH_4/CM, and as no study has previously reported this, we also estimated CH_4 intensity per kilogram of fresh cheese ($\mathbf{CH_4/CY_{CURD}}$, g/kg) and cheese solids ($\mathbf{CH_4/CY_{SOLIDS}}$, g/kg) using the cheese yield (**CY**) obtained from model cheeses made from milk samples from every individual cow.

Following previous research, the objective of the present study was to compare 5 reference EME traits, estimated on the basis of FA_{GC} and individual CY, with the same EME traits predicted directly by IR spectrometry from milk spectra, or indirectly calculated on the basis of other IR-predicted traits (FA_{IR}, CY, dCMY). The EME traits studied were CH_4 production (g/d), CH_4 intensity (g/kg) per unit of milk, fresh cheese and cheese solids, and CH_4 yield (g/kg) expressed per unit of DMI.