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# Encapsulated fumaric acid as a feed ingredient to decrease ruminal methane emissions

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ABSTRACT

Decreasing methanogenesis in ruminants would benefit the agricultural industry because it would lead to lower energy losses from the animals as well as being beneficial for the environment in decreasing emissions of a greenhouse gas. Fumaric acid (FA) as a feed supplement has the potential to decrease methane production as well as increase glucogenesis and hence milk yield, but the quantity fed has to be restricted because of a risk of acidosis and a consequent decrease in fibre breakdown and feed intake. The objective of this study was to determine if FA encapsulated in partially hydrogenated vegetable oil (PHVO) could decrease methane formation without the problematic effects on ruminal pH. A commercial sample of encapsulated fumaric acid (EFA) did not affect pH and maintained propionate production when added *in vitro* to ruminal fluid from sheep receiving 49:51 grass hay:concentrate, and it suppressed methane formation by 19% ($P<0.05$). Different formulations of encapsulated fumaric acid were also effective. *In vivo*, growing lambs on a concentrate diet with straw *ad libitum* produced 24.6 L/d of methane, whereas a 100 g/kg addition of FA or EFA decreased ($P<0.001$) methane production to 9.6 and 5.8 L/d, respectively. Live weight gain over 43 d was 184, 165 and 206 g/d ($P=0.267$) while feed conversion was 135, 137 and 159 g gain/kg feed intake ($P=0.605$) in control, FA and EFA groups, respectively. The 76% decrease in methane described here, one of the largest reported to

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date, exceeds the inhibition that might be expected from purely stoichiometric considerations, suggesting an adaptive effect on the rumen microbial community.



## 1. Introduction

Methane is an important greenhouse gas, which contributes approximately 19% to the overall radiative forcing (Wuebbles and Hayhoe, 2002; Lassey, 2008). Anthropogenic sources, including emissions from ruminants, contribute 14% to the overall radiative forcing with 90% of the ruminant contribution coming from cattle (Johnson and Ward, 1996; Lassey, 2008). Although the contribution of ruminants equates to only 3% of the overall radiative forcing, it is more easily manipulated than the greatest anthropogenic source of methane (mining and processing of fossil fuels, 4%; Wuebbles and Hayhoe, 2002) and controlling ruminal methanogenesis would help achieve the objectives set by the Kyoto Protocol for global reductions in methane emissions at 5.2% below the 1990 level for the period 2008–2012 (Moss et al., 2000).

As well as the environmental benefits, the efficiency of livestock production would benefit from decreased methane emissions. Methane formed in the forestomachs of ruminants during fermentation of the feed can represent an energy loss to the animals of 5–15% (Czerkawski, 1969) depending on the type of diet. This problem has been recognised for many years, and many feed additives have been studied for their ability to decrease the loss of energy through methane, including halogenated compounds (McSweeney and McCrabb, 2002; Agarwal et al., 2008), analogues of cofactors involved in methane synthesis (Nagaraja et al., 1997), ionophores (Grainger et al., 2008; Waghorn et al., 2008), yeast (Beauchemin et al., 2008), lipids (Van Nevel and Demeyer, 1996; Fievez et al., 2003; Beauchemin et al., 2007), and plants and plant extracts such as essential oils (Rochfort et al., 2007; Chaves et al., 2008; Kamra et al., 2008).

One of the most promising strategies for decreasing methane formation, as an alternative to inhibiting methane formation directly, is to redirect the $H_2$ away from methane formation, either by acetogenesis (Fievez et al., 1999; López et al., 1999; McAllister and Newbold, 2008) or by the use of organic acids as alternative hydrogen sinks (López et al., 1999; Ungerfeld et al., 2003; Castillo et al., 2004). Fumaric acid is most commonly used (Martin, 1998; Hino and Asanuma, 2003; McAllister and Newbold, 2008). It is reduced by $H_2$ or 2H to succinate, which is then converted to propionate, which benefits the animal (Steinhour and Bauman, 1998; Kim et al., 2001). One mole of fumaric acid (FA) may therefore divert a maximum of one mole of $H_2$ away from methane formation. It follows that, in order to prevent the formation of one mole of methane, four times as much FA on a molar basis must be added to the feed. In fact, FA is not converted quantitatively to propionate (Callaway and Martin, 1996; López et al., 1999; Carro and Ranilla, 2003; García-Martínez et al., 2005; Gomez et al., 2005), so the efficiency of trapping hydrogen is lower than 100%. Thus, although there is evidence to suggest that FA could be used to decrease methane production in beef cattle (Castillo et al., 2004), the quantity of the free acid fed has to be restricted, because of the drop in ruminal pH (Asanuma et al., 1999) and inappetence problems (Castillo et al., 2004). A possible solution to this problem is to feed salts of fumaric acid (Newbold et al., 2005), such as sodium fumarate. However, the osmotic load imposed by the large addition of sodium to the diet would be better avoided. The aims of the present study were to determine if, by encapsulating fumaric acid to slow its release in the rumen, methane formation might be inhibited without affecting ruminal pH and to evaluate how encapsulated fumaric acid (EFA) affected methane formation and performance in growing lambs.

## 2. Materials and methods

### 2.1. Encapsulated fumaric acid

A commercial preparation of EFA, containing 830–870 g/kg FA and 17–13 g/kg partially hydrogenated vegetable oil (PHVO) was used in most of the experiments (Bakeshure 451; Balchem, NY,