Medium chain fatty acid feed supplementation reduces the probability of Campylobacter jejuni colonization in broilers

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1. Introduction

Meat products from broilers colonized with Campylobacter jejuni are considered an important source of human campylobacteriosis (Friedman et al., 2004), and reduction of human exposure is an important goal of public health programs (EFSA, 2005). One way to achieve this is to prevent intestinal colonization of broilers with Campylobacter spp., either by prevention of exposure or by reducing the susceptibility for colonization (Wagenaar et al., 2006). Because highly effective biosecurity measures to prevent exposure might be difficult to implement, reduction of susceptibility of broilers for colonization, here defined as the probability of colonization upon exposure, may be an alternative way to reduce the number of colonized flocks.
One way to reduce the susceptibility is to change the micro-environment in the gastro-intestinal tract in such a way that ingested *Campylobacter* bacteria are inactivated or unable to reach the lower intestines. It has been shown that short and medium chain fatty acids (SCFA and MCFA, respectively) have *in vitro* anti-*Campylobacter* activity that is additional to the *Campylobacter* inactivating effect of an acidified micro-environment (Chaveerach *et al.*, 2002; Thormar *et al.*, 2006). *In vivo*, feed supplemented with high level SCFA results in a reduced chance of colonization in broilers, but also in reduced body weight gain (BWG), which is economically undesirable (Heres *et al.*, 2004). Lower fatty acid concentrations might be necessary to prevent BWG loss, preferably combined with improved effectivity at higher pH, to extend the anti-*Campylobacter* activity throughout a larger part of the gastro-intestinal tract.

Whereas SCFA activity ceases at pH $>5.5$ (Chaveerach *et al.*, 2002), *in vitro* studies showed that 1-monoglyceride of capric acid, a MCFA, has anti-*Campylobacter* activity in feed mixed with a buffer at pH 5.5 and in feed mixed with tap water at pH 7.0 (Thormar *et al.*, 2006). Consequently, MCFA might inactivate *Campylobacter* cells in the crop (pH 4.5) and the intestines, where the pH is approximately 5.8–6.0 (Chang and Chen, 2000; Farner, 1942). A low concentration mixture of MCFA could therefore be a promising tool to decrease the susceptibility without negative effects on weight gain or feed conversion.

The aim of this study was to determine whether an acidified feed containing 1% MCFA was able to reduce the susceptibility of broilers for colonization with *C. jejuni*. Additionally, the effects of supplemented feed on BWG and feed conversion rate (FCR) were determined.

2. Material and methods

2.1. Experimental design

Two experiments were carried out subsequently. For each experiment hatching eggs, originating from one commercial broiler breeder flock (Ross 308) were purchased at 17 days of incubation. Chicks were hatched at the experimental facilities of the Faculty of Veterinary Medicine of Utrecht University. After hatching broilers were randomly assigned to control feed (CF) or supplemented feed (SF), which they received throughout the experiments. CF was an antibiotic and anti-coccidia drug free, mashed diet. SF was the same diet, with 1% soybean oil substituted by 1% Lodestar™ C8–10 (Loders Croklaan, Wormerveer, The Netherlands), which is produced by fractional distillation of palm kernel oil free fatty acids, and typically consists of 56% $C_{10}$, 30% $C_8$, 10% $C_{12}$, <3% $C_6$, and <3% other lipids. The composition and calculated chemical analyses of both diets are shown in Table 1.

In experiment 1 (exp. 1), a group of 150 day-old chicks was provided CF, based on random selection of the birds, and a group of 47 chicks was provided SF. In experiment 2 (exp. 2), chicks were placed in multiple groups: 192 day-old chicks were randomly divided into 32 groups of 6 chicks each, 22 groups receiving CF (132 chicks) and 10 groups SF (60 chicks). Birds were housed in a well-controlled facility, on litter floors. Groups were separated by walls. Water and feed were available ad libitum, and from 7 days of age a daily dark period of 6 h was applied.

At 14 days of age, by random selection 114 of the initially 150 CF and 42 of 47 SF broilers (exp. 1), and 113 of 132 CF and 43 of 60 SF broilers (exp. 2) were weighed and housed individually in wired cages of $40 \times 40$ cm, with closed, littered floors, which were situated in four identical compartments. In exp. 1, broilers in both treatment groups were randomly divided over the cages in all compartments. In exp. 2, broilers per treatment group were evenly divided over the compartments, and within each compartment, broilers were randomly assigned to cages. The sides and back of each cage were covered with plastic sheets. The distance between the cages was 40 cm at least.

2.2. Inoculation

One dose of $10^9$ CFU of *C. jejuni* C356, originating from a broiler flock (Jacobs-Reitsma *et al.*, 1995) and stored in glycerol at $-80\, ^\circ C$, was orally administered to 3 five-day-old broilers, which were housed with 3 non-inoculated contact broilers. Three days post-inoculation (PI) *C. jejuni* was isolated from the ceca of one contact broiler. This chicken-passaged strain, here referred to as *C. jejuni* C356P (C356P), was stored in glycerol at $-80\, ^\circ C$ and used in experiments 1 and 2.

Before inoculation, C356P was freshly cultured in Heart Infusion Broth (micro-aerobically, 37 °C, overnight) and diluted in saline to obtain the intended inoculation doses. Based on power calculations, using results from a pilot study (data not shown), and presuming an additive effect on the inoculation dose required to colonized 50% of the birds ($CD_{50}$) of approximately $\log_{10}1.5$ CFU, SF broilers

<table>
<thead>
<tr>
<th>Ingredient composition and calculated analysis of the diets.</th>
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<tbody>
<tr>
<td>Item</td>
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<tr>
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</tr>
<tr>
<td>Wheat</td>
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<tr>
<td>Soybean meal</td>
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<td>Corn</td>
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<tr>
<td>Peas</td>
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<tr>
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<tr>
<td>Calcium carbonate</td>
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<td>MCFA</td>
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<tr>
<td>Monocalcium phosphate</td>
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<tr>
<td>Lysine 65%</td>
</tr>
<tr>
<td>Sodium chloride</td>
</tr>
<tr>
<td>Methionine</td>
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<tr>
<td>Premix</td>
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<tr>
<td>Sodium bicarbonate</td>
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<td>Threonine</td>
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<td>Choline chloride</td>
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<td>Endoxylanase</td>
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<td>Phytase</td>
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</tbody>
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* MEₙ (kcal/kg) | 2790 | 2790 |

* a Energetic value of MCFA and soybean oil was assumed to be equal.
  b 1% Lodestar™ C8–10.
were inoculated with higher doses C356P than CF broilers (Table 2). In each compartment, non-inoculated broilers were housed in four randomly selected cages (sentinel) to detect Campylobacter transmission. Broilers, except sentinels, were orally inoculated with 0.25 ml of the C356P inoculation suspensions at 14 days of age (exp. 1; n = 140) or 18 days of age (exp. 2; n = 139; one broiler died 1 day prior to inoculation). The inoculation doses were randomly divided over the compartments. To limit variation between individuals, all broilers were feed-deprived for 11 h prior to inoculation, and provided feed directly afterwards. The concentration of Campylobacter in the administered inocula was determined by plating on modified charcoal cefoperazone deoxycholate agar (mCCDA) (Biotrading, Mijdrecht, The Netherlands). Colonization status of broilers (exp. 1 and exp. 2).

### Table 2

<table>
<thead>
<tr>
<th>Exp. 1</th>
<th>Treatment group</th>
<th>Dose C356P</th>
<th>Time (days PI)</th>
<th>Exp. 2</th>
<th>Treatment group</th>
<th>Dose C356P</th>
<th>Time (days PI)</th>
</tr>
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<tbody>
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<td></td>
<td></td>
<td>4 / 14</td>
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<td>4 / 14</td>
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<tr>
<td>CF</td>
<td>–</td>
<td>0/16</td>
<td>0/16</td>
<td>CF</td>
<td>–</td>
<td>0/16</td>
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<tr>
<td>CF</td>
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<td>0/33</td>
<td>1/32⁺</td>
<td>CF</td>
<td>1.47</td>
<td>8/32</td>
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<tr>
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<td>3/33</td>
<td>12/32⁺</td>
<td></td>
<td>2.47</td>
<td>21/33</td>
<td>25/33</td>
</tr>
<tr>
<td></td>
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<td>20/32</td>
<td>21/31⁺</td>
<td></td>
<td>3.47</td>
<td>30/32</td>
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<tr>
<td>SF</td>
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<td>2/21</td>
<td>SF</td>
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<td>9/20⁺</td>
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<td>5.47</td>
<td>9/11</td>
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</tbody>
</table>

Rows represent different feed treatment groups (CF = control feed; SF = supplemented feed) and C. jejuni C356P inoculation doses (log₁₀ CFU/broiler). Nominators in cells express the number of broilers detected Campylobacter-positive, and denominators express the number of broilers sampled throughout 4 or 14 days post-inoculation (PI).

⁺ A broiler died after being tested positive at 4 dpi.

### 2.3 Sampling and testing

Six (exp. 1) or seven days (exp. 2) prior to inoculation, broilers were tested for the presence of Campylobacter by culture of a fecal dropping on mCCDA. All broilers tested negative. After inoculation, birds were sampled at 4, 8, and 11 days post-inoculation (PI) by swabbing fresh cecal droppings if present, or otherwise a swab of a fresh fecal dropping. If neither could be obtained, a swab from cloacal content was taken. In addition, at 1, 2, 3, 7, and 9 days PI 1 sentinel per compartment and 1–5 inoculated broilers per inoculation dose were placed in cardboard boxes with wire floors for 4 h, to collect cloacal swabs and fresh cecal droppings (or fecal droppings if not present). Different material was sampled with the intention to compare the sensitivity of each of these sampling methods. Because positivity was limited to one of two sample types only incidentally, sensitivity of different sample mediums was considered equal. At the end of the trial (14 days PI), cecal contents were sampled after euthanasia by cervical dislocation.

The person sampling the broilers was blinded to dose groups and could not distinguish sentinels from inoculated broilers. Long-sleeved plastic gloves were changed for each broiler to avoid cross-contamination. Samples were collected with sterile swabs and transported to the laboratory in modified Amies transport medium without charcoal (Biotrading, Mijdrecht, The Netherlands) within 6 h. Samples were streaked on mCCDA plates and incubated micro-aerobically at 42 °C and examined for the presence of Campylobacter-suspect colonies after 24 and 48 h. Microscopic examination of morphology and motility was used as confirmation. Broilers were considered Campylobacter-colonized and were excluded from further sampling when at least one sample tested positive. Ethical aspects of the experiments were judged and approved by the animal ethical committee of Utrecht University.

To assess the effect of MCFA feed supplementation on technical performance, BWG and feed intake during the period of individual housing (>14 days of age) were recorded in exp. 2.

### 2.4 Statistical analyses

The effect of MCFA feed supplementation on susceptibility was assessed by fitting a beta-binomial dose–response model (Teunis and Havelaar, 2000). According to this model, inoculation with dose D results in a probability of colonization Prinoc(D):

\[
Pr_{\text{inoc}}(D) = 1 - \left(1 + \frac{D}{B}\right)^{-\alpha}
\]

The underlying assumption of the model is that each bacterium can independently establish colonization, but that hosts may differ in their susceptibility (Teunis and Havelaar, 2000). The two parameters (instead of single probabilities for each dose) provide opportunities to assess the dose–response relation over a wide range of exposure doses, and to compare treatments tested with different ranges of inoculation doses. Furthermore, the dose–response model could be used to calculate a CD₅₀: the colonization dose resulting in a 50% probability of infection.

Because sentinels were detected positive after day 4 PI in exp. 2 (Table 2), colonization as a result of transmission could not be excluded for the inoculated birds either. Therefore, in the main analysis (using data up to day 14 PI)
we corrected for transmission by estimating a transmission probability \( Pr_t \), different for each room and treatment group. Consequently \( Pr_t(D) \), the probability of being colonized, was equal to

\[
Pr_t(D) = 1 - (1 - Pr_{inoc}(D))(1 - Pr_{inoc}(D))
\]

Additionally, a more simple analysis was performed using the colonization status up to day 4 Pl, without the correction for transmission. In the day-4 analysis, \( Pr_t(D) \) was equal to \( Pr_{inoc}(D) \).

For both analyses (day 4 and day 14), four different models were fitted to see if there were group and treatment effects: the first with separate dose–response relations for each of the four treatment groups (CF1 vs. CF2 vs. SF1 vs. SF2), the second with combined CF groups (CF12) vs. combined SF groups (SF12), the third with combined exp. 1 groups vs. exp. 2 groups, and the fourth with all groups combined.

All parameters were estimated by maximum likelihood. The corrected Akaike Information Criterion (AICc) (Hurvich and Tsai, 1989) was used to decide which model explained the data best and whether different dose–response relations should be adopted for (combined) treatment groups.

Prior to inoculation, some groups of broilers got diarrhea at 1 week of age. To study the possible confounding effect of diarrhea on susceptibility, data of exp. 2 were analyzed as described above, in four groups, with diarrhea status instead of experiment. AICc was used to assess if the occurrence of this symptom was associated with an increased or decreased susceptibility to Campylobacter colonization.

Linear regression analyses (SPSS 15.0.1.) were performed to assess if feed treatment affected BWG and FCR in exp. 2. Sixty-nine broilers, which were detected Campylobacter-colonized before or at 4 days Pl, were weighed and sexed at 28 days of age, while the remaining 84 broilers (19 colonized and 65 non-colonized) were weighed and sexed at 32 days of age. To correct for this, age and final colonization status were included as dependent variables, next to the variables sex and feed treatment, resulting in the equations

\[
BWGi = \beta_0 + \beta_1 \text{Feedi} + \beta_2 \text{Sexi} + \beta_3 \text{Agei} + \beta_4 \text{Coli} + \epsilon_i,
\]

and,

\[
FCRj = \beta_0 + \beta_1 \text{Feedj} + \beta_2 \text{Sexj} + \beta_3 \text{Agej} + \beta_4 \text{Colj} + \epsilon_j.
\]

3. Results

3.1. Colonization

In exp. 1, 35 of 46 colonized birds, and in exp. 2, 72 of 89 colonized birds were detected Campylobacter-positive in the first 4 days Pl (Table 2). In exp. 1, the sentinels remained negative, but in exp. 2, 4 of 16 sentinels were detected Campylobacter-positive, at 7, 8, and 14 days Pl. Four birds in exp. 1 and one bird in exp. 2 died after day 4 Pl (Table 2).

3.2. Dose–response: effect on susceptibility

The best fitting day-14 model (lowest AICc) included separate dose–response relation for CF12 and SF12, indicating equal relations in both experiments. Dose–response relations of CF12 and SF12 show parallel sigmoid shapes (Fig. 1). CD50 for CF12 was log_{10} 2.5 CFU (95% CI: 2.2–2.8) and CD50 for SF12 was log_{10} 4.8 CFU (95% CI: 4.4–5.2) (Fig. 1). The AICc of alternative models was at least 3.95 higher.

The best day-4 model included separate dose–response relations for all four treatment groups (CF1, CF2, SF1, and SF2). CD50 for CF1 and CF2 were log_{10} 2.8 CFU (95% CI: 2.6–3.3) and 2.1 CFU (95% CI: 1.8–2.3), respectively. CD50 for SF1 and SF2 were log_{10} 8.5 CFU (95% CI: 4.8–∞) and 4.7 CFU (95% CI: 4.2–5.2), respectively. The AICc of alternative models was at least 12.2 higher.

In exp. 2, diarrhea occurred around 1 week of age, with similar frequencies in both treatment groups (14/22 CF groups and 5/10 SF groups; Fisher’s exact test: \( p = 0.70 \)), suggesting that diarrhea was not feed related. In a separate analysis of data of exp. 2 inclusion of a variable describing whether a broiler originated from a group with diarrhea did not result in a better fit, with AICc being approximately 4 points higher in both the day-4 and day-14 models.

3.3. Effect on technical performance

The broiler that died during exp. 2 (Table 2) and a broiler that was lame during the last few days of the experiment were excluded from this analysis. BWG was estimated 49 ± 24 g higher in SF broilers compared to CF broilers (\( p = 0.044 \)) when correcting for the effect of sex (\( p < 0.001 \)), age (\( p < 0.001 \)), and final colonization status (\( p = 0.398 \)). FCR was estimated 0.061 ± 0.034 lower in broilers which were provided supplemented feed (\( p = 0.075 \)) when correcting for sex (\( p = 0.179 \)), age (\( p = 0.183 \)), and final colonization status (\( p = 0.735 \)).
inoculation dose and the subsequent occurrence of colonization, resulting in dose–response curves of SF broilers shifted to the right compared to CF broilers, indicating that SF broilers required a higher inoculation dose to become colonized than CF broilers. The effect of MCFA feed supplementation could also have been assessed by comparing the percentage of colonized broilers exposed to equal inoculation doses (log_{10} 2.19 CFU in exp. 1, and log_{10} 2.47 and 4.37 CFU in exp. 2) at 14 days PI (Table 2). Although this would also have illustrated the susceptibility reducing effect of the treatment (Fisher’s exact test: all p < 0.05), we would not have been able to predict the probability of colonization for other inoculation doses, nor would we have been able to correct for transmission.

We used the beta-binomial dose–response model (Teunis and Havelaar, 2000) to estimate dose–response curves and CD_{50s}. Besides the fact that this analysis resulted in less parameters to be estimated than separate analyses for different doses, and in the possibility to use different doses for different treatments, it also turned out useful to correct for transmission. We used the colonization status at 14 days PI to estimate the dose–response relations, but when the Campylobacter colonization status at 4 days PI was used in the alternative (day-4) model, similar estimates were obtained. This similarity suggests that most broilers colonized after 4 days PI were colonized by transmission. Based on the results in this study, challenge experiments with Campylobacter might not necessarily have to last longer than 4 days to estimate the dose–response relation properly.

Analysis of technical performance showed that BWG was increased in SF broilers, while FCR was not affected. The effect on BWG might have been caused by antimicrobial effects of the fatty acids, as feed supplementation with capric acid and lauric acid, two MCFA, has been shown to decrease the concentration of Clostridium perfringens in jejunum and ileum of C. perfringens challenged broilers (Jansman et al., 2006). Although feed supplementation with antimicrobial agents has the potential to improve feed efficiency (Dibner and Richards, 2005; Jansman et al., 2006), in this study no significant effect on FCR was observed.

5. Conclusion

The number of C. jejuni bacteria required to colonize 50% of inoculated broilers was estimated 200 times higher in broilers fed with supplemented feed than in control broilers. Although the working mechanism of supplemented feed remains to be elucidated, this effect on susceptibility is a promising finding for the implementation of MCFA feed supplementation as an intervention for reduction of susceptibility in broilers. As the Campylobacter exposure dose that broilers experience in the field is unknown, field trials are necessary to determine to what extent MCFA supplementation reduces Campylobacter colonization in the field.

References


