Efficacy of thymol as a practical, cost-effective, easy administer prebiotic

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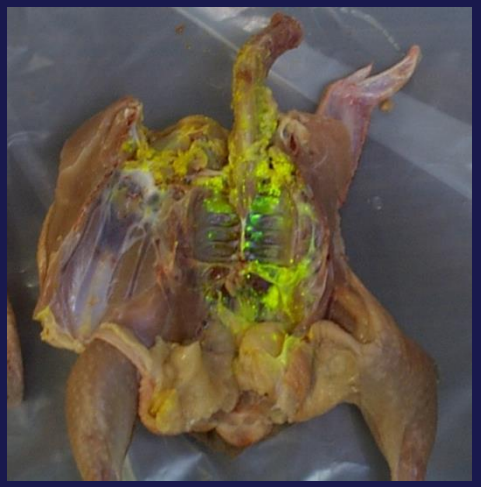
Mission of the USDA/ARS Research Team in College Station:

Develop interventions to reduce epizootic pathogenic bacteria in swine and cattle

Need for interventions



Byrd et al. 2002. Poultry Sci. 81: 70-74

- The gut of food producing animals and their production environment can be reservoirs for foodborne pathogens and antimicrobial resistant microbes
  - Foodborne pathogens and resistant bacteria can contaminate the carcass and can be disseminated in environment

- Postharvest interventions are running against a wall (i.e., hard to get cleaner and better)
- Consumer demand for safe, high quality product

- **INCREASING PRESSURE TO REMOVE ACCESS TO ANTIBIOTICS**

Preferred Qualities of Preharvest Interventions and Antibiotic Alternatives

- Low cost and practical
- Easy to handle and administer
- Efficacious and safe
- Mechanistic and specific
- Amendable to varied production practices
- Cost recoverable

Practical challenges to development of usable interventions

- interventions should, where possible, provide incentives for implementation by reducing costs associated with production inefficiencies and environmental emissions (increase production of high quality products with less environmental footprint).

- research should be balanced to include work with technologies near to market such as those Generally Recognized As Safe (GRAS), as well as fundamental research to elucidate mechanistically-defined interventions that can ultimately be exploited to provide efficacy over the long-term.

Research with Essential Oils

Attractiveness of Essential Oils

PRACTICE TIP — PEER REVIEWED

Feed additives for swine: Fact sheets – prebiotics and probiotics, and phytogenics

Jay Y. Jacela, DVM, PhD; Joel M. DeRouchey, PhD; Mike D. Tokach, PhD; Robert D. Goodband, PhD; Jim L. Nelssen, PhD; David G. Renter, DVM, PhD; Steve S. Dritz, DVM, PhD

Natural compounds that have history of use and may be viewed favorably by FDA

FACT Sheet: Phytogenic feed additives (phytobiotics or botanicals)

Restriction on the use of in-feed antibiotics in many countries has fueled the interest in alternative products. A group of natural products known as phytogenics has been the focus of several studies in recent years.[1] Also referred to as phytobiotics or botanicals, phytogenics are plant-derived products used in feed to potentially improve pig performance. Aside from having antimicrobial activity, these products potentially provide antioxidative effects, enhance palatability, improve gut functions, or promote growth.[1] However, there is limited research validating their potential benefits for pigs.

Fast facts

Phytogenic feed additives are substances derived from plants.

The potential benefits of phytogenics in pig diets have not been fully substantiated.

Current research data show that growth responses to phytogenic feed additives are still inadequate compared to responses obtained with the use of in-feed antimicrobials.

What products are being used as phytogenic feed additives?

Phytogenics comprise a wide range of substances and thus have been further classified according to botanical origin, processing, and composition. Phytogenic feed additives include herbs, which are non-woody flowering plants known to have medicinal properties; spices, which are herbs with intensive smell or taste, commonly added to human food; essential oils, which are aromatic oily liquids derived from plant materials such as flowers, leaves, fruits, and roots; and oleoresins, which are extracts derived by non-aqueous solvents from plant material.[1] Two of the most common phytogenic substances evaluated in swine include the spices oregano and thyme.[1-5]

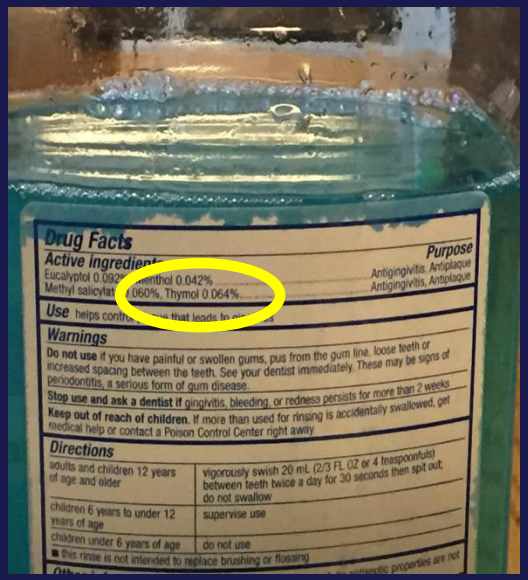
How do phytogenic feed additives exert their claimed effects?

The mode of action of most phytogenic feed additives is still not fully understood. However, the following are some of the potential mechanisms by which they may improve performance.

Increased feed intake. The stimulatory effect of phytogenics on

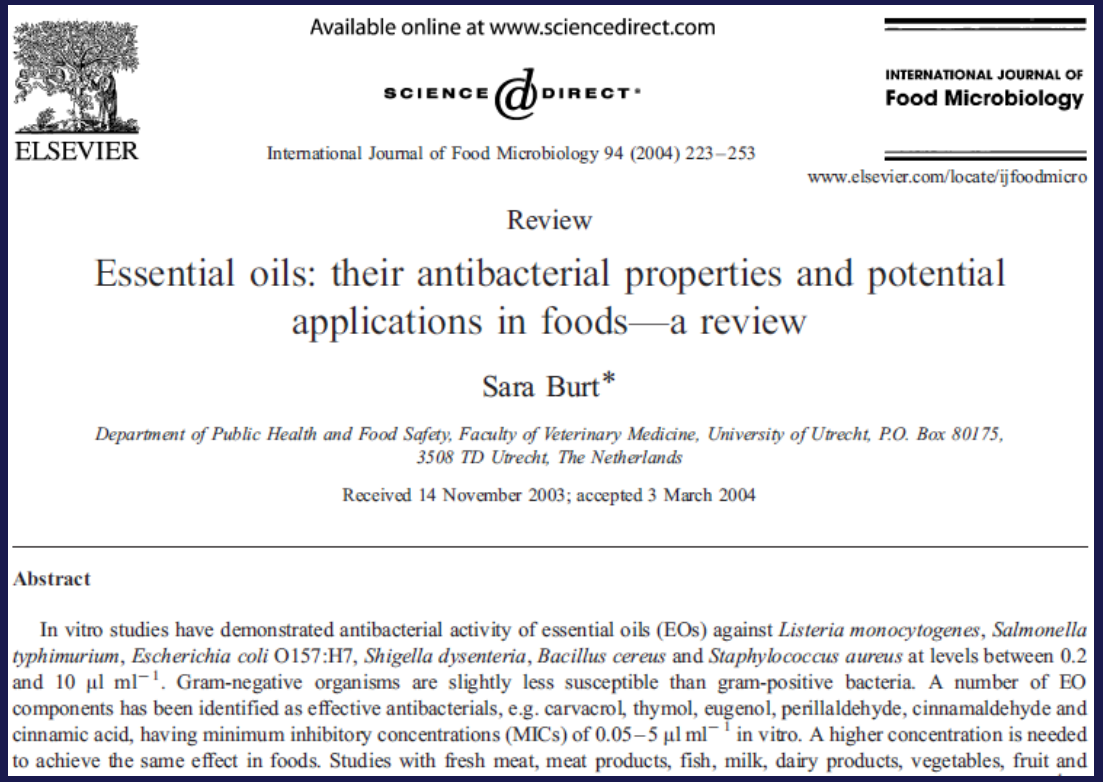
Anti-oxidative effects. Anti-oxidative properties of some phytogenic substances have been attributed to the phenolic terpenes in the essential oils.[17,18] Essential oils of plants belonging to the Labiatae family have been widely used as antioxidants in human and pet foods with high fat content.[10] Plants high in terpenes include rosemary, oregano, and thyme.[1,10] However, whether they can be added in amounts sufficient to replace the effects of antioxidants commonly used in pig diets, such as ethoxyquin and butylated hydroxytoluene, remains to be seen.

Antimicrobial effect. The medicinal or antimicrobial properties of plant-derived substances have been well known for centuries.[19,20] This property is mainly attributed to the essential oils of these plants. Oregano and thyme are among those which have received a great deal of interest. These plants contain the monoterpenes carvacrol and thymol, respectively, and have demonstrated



Consequently may be more near to market than strategies requiring FDA approval

Mechanism of thymol and other essentials oils



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INTERNATIONAL JOURNAL OF Food Microbiology

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International Journal of Food Microbiology 94 (2004) 223–253

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Review

Essential oils: their antibacterial properties and potential applications in foods—a review

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Received 14 November 2003; accepted 3 March 2004

Abstract

In vitro studies have demonstrated antibacterial activity of essential oils (EOs) against *Listeria monocytogenes*, *Salmonella typhimurium*, *Escherichia coli* O157:H7, *Shigella dysenteria*, *Bacillus cereus* and *Staphylococcus aureus* at levels between 0.2 and 10 μl ml^{-1}. Gram-negative organisms are slightly less susceptible than gram-positive bacteria. A number of EO components has been identified as effective antibacterials, e.g. carvacrol, thymol, eugenol, perillaldehyde, cinnamaldehyde and cinnamic acid, having minimum inhibitory concentrations (MICs) of 0.05–5 μl ml^{-1} in vitro. A higher concentration is needed to achieve the same effect in foods. Studies with fresh meat, meat products, fish, milk, dairy products, vegetables, fruit and

- Thymol
- Carvacrol
- Eugenol
- Perillaldehyde
- Cinnamaldehyde
- Cinnamic acid

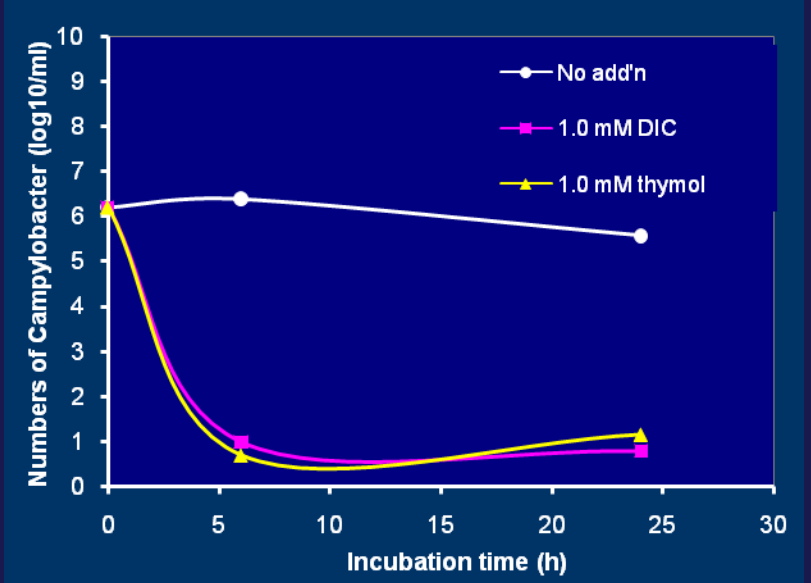
MIC's of 0.05 to 5 μl/mL against pure cultures

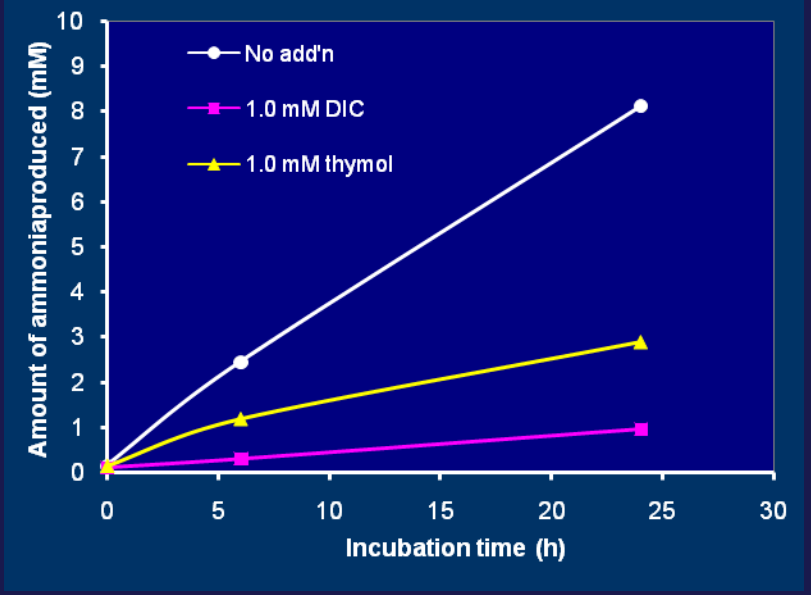
-higher concentrations needed when applied to foods

-mechanistically, thought to disrupt cell walls

Early evidence testing inhibitors of amino acid metabolism revealed that thymol can reduce survivability of *Campylobacter*

- Thymol and Diphenyliodonium chloride (DIC) have been studied extensively for ability to reduce the inefficiency of ruminal amino acid catabolism (Chalupa et al., 1980's)

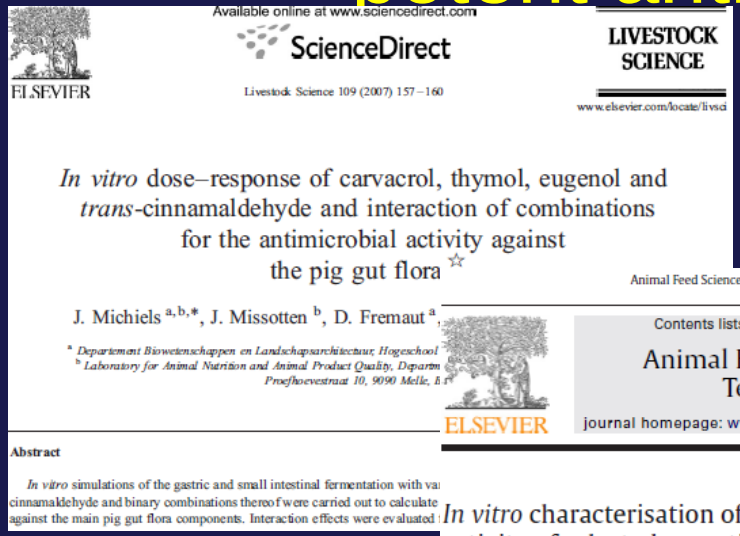




Results with swine gut populations confirmed that thymol and DIC knock the "heck" out of *Campylobacter* and ammonia production in mixed culture

This Project was funded by the National Pork Board.

Numerous in vitro (bench top) studies have shown essential oils such as thymol to exhibit potent antimicrobial activity



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Livestock Science 109 (2007) 157–160

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In vitro dose–response of carvacrol, thymol, eugenol and *trans*-cinnamaldehyde and interaction of combinations for the antimicrobial activity against the pig gut flora ☆

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Abstract

In vitro simulations of the gastric and small intestinal fermentation with va
cinnamaldehyde and binary combinations thereof were carried out to calculate
against the main pig gut flora components. Interaction effects were evaluated

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In vitro characterisation of the antimicrobial activity of selected essential oil components and binary combinations against the pig gut flora

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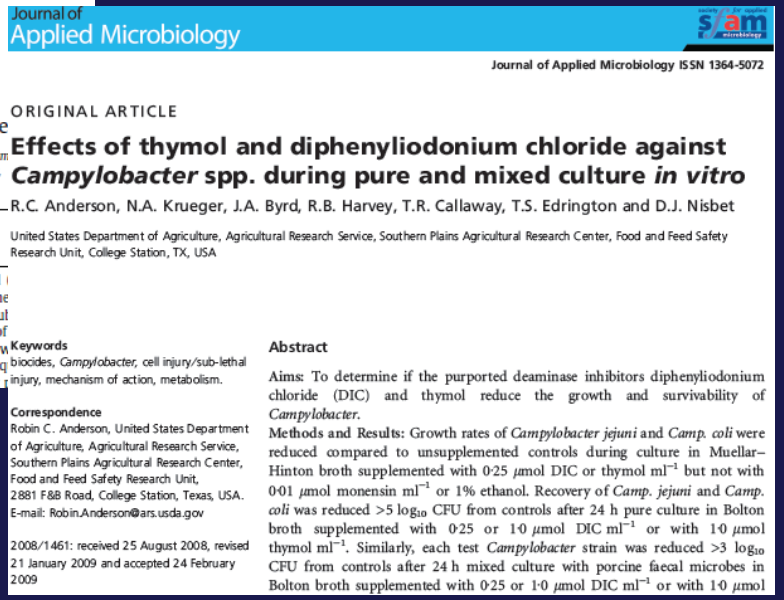
In vitro antimicrobial activity

ABSTRACT

The antimicrobial activity of selected essential oil
nents against the major culturable components of the
has been characterised by means of an *in vitro* incul
simulating the fermentation in different sections of
trointestinal tract (GIT). In a first study 7 components w
for their antimicrobial properties. Dose–response eq
established for the 4 components with the highest



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ORIGINAL ARTICLE

Effects of thymol and diphenyliodonium chloride against *Campylobacter* spp. during pure and mixed culture *in vitro*

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Keywords
biocides, *Campylobacter*, cell injury/sub-lethal injury, mechanism of action, metabolism.

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2008/1461: received 25 August 2008, revised 21 January 2009 and accepted 24 February 2009

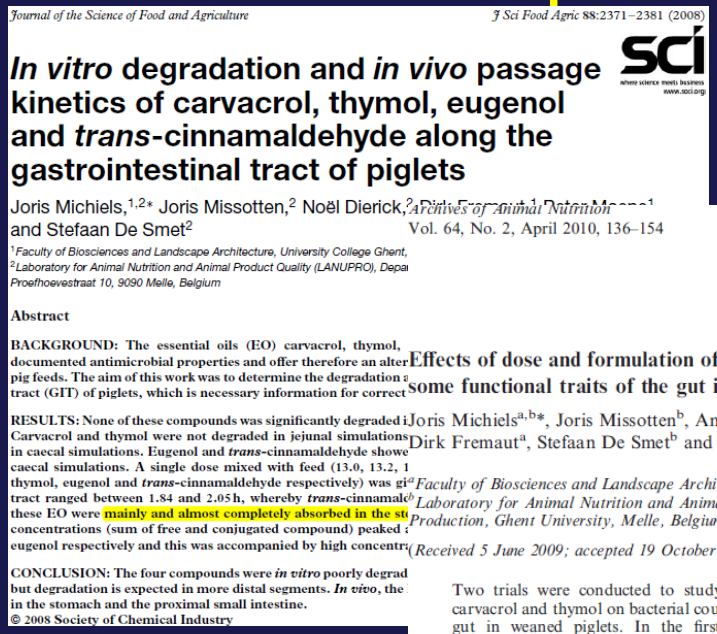
Abstract

Aims: To determine if the purported deaminase inhibitors diphenyliodonium chloride (DIC) and thymol reduce the growth and survivability of *Campylobacter*.

Methods and Results: Growth rates of *Campylobacter jejuni* and *Camp. coli* were reduced compared to unsupplemented controls during culture in Muellar–Hinton broth supplemented with 0·25 μmol DIC or thymol ml^{-1} but not with 0·01 μmol monensin ml^{-1} or 1% ethanol. Recovery of *Camp. jejuni* and *Camp. coli* was reduced >5 log_{10} CFU from controls after 24 h pure culture in Bolton broth supplemented with 0·25 or 1·0 μmol DIC ml^{-1} or with 1·0 μmol thymol ml^{-1}. Similarly, each test *Campylobacter* strain was reduced >3 log_{10} CFU from controls after 24 h mixed culture with porcine faecal microbes in Bolton broth supplemented with 0·25 or 1·0 μmol DIC ml^{-1} or with 1·0 μmol

The work in this bottom paper was funded in part by the National Pork Board.

Limitations of essential oils like thymol as feed additives is that they are extensively degrade or absorbed in proximal gastrointestinal tract



Journal of the Science of Food and Agriculture J Sci Food Agric 88:2371–2381 (2008)

In vitro degradation and _in vivo_ passage kinetics of carvacrol, thymol, eugenol and _trans_-cinnamaldehyde along the gastrointestinal tract of piglets

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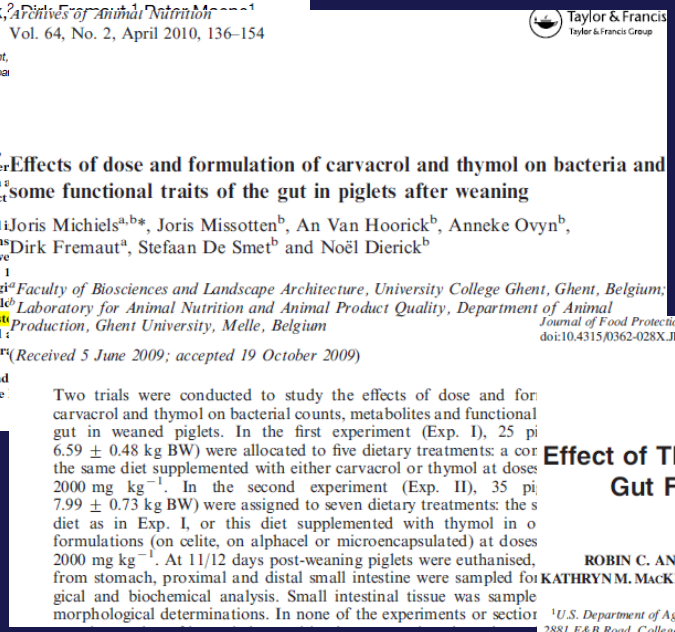
Abstract

BACKGROUND: The essential oils (EO) carvacrol, thymol, documented antimicrobial properties and offer therefore an alter pig feeds. The aim of this work was to determine the degradation tract (GIT) of piglets, which is necessary information for correct

RESULTS: None of these compounds was significantly degraded i Carvacrol and thymol were not degraded in jejunal simulations in caecal simulations. Eugenol and _trans_-cinnamaldehyde showe caecal simulations. A single dose mixed with feed (13.0, 13.2, 1 thymol, eugenol and _trans_-cinnamaldehyde respectively) was gi tract ranged between 1.84 and 2.05 h, whereby _trans_-cinnamalc these EO were mainly and almost completely absorbed in the st concentrations (sum of free and conjugated compound) peaked eugenol respectively and this was accompanied by high concentr

CONCLUSION: The four compounds were _in vitro_ poorly degrad but degradation is expected in more distal segments. _In vivo_, the in the stomach and the proximal small intestine.



Archives of Animal Nutrition Taylor & Francis
Vol. 64, No. 2, April 2010, 136–154

Effects of dose and formulation of carvacrol and thymol on bacteria and some functional traits of the gut in piglets after weaning

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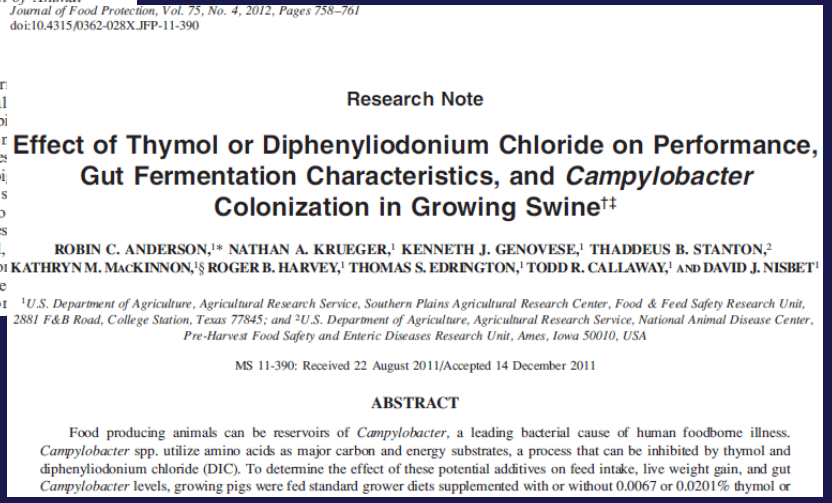
(Received 5 June 2009; accepted 19 October 2009)

Two trials were conducted to study the effects of dose and for carvacrol and thymol on bacterial counts, metabolites and functional gut in weaned piglets. In the first experiment (Exp. I), 25 pi 6.59 ± 0.48 kg BW) were allocated to five dietary treatments: a cor the same diet supplemented with either carvacrol or thymol at doses 2000 mg kg^{-1}. In the second experiment (Exp. II), 35 pi 7.99 ± 0.73 kg BW) were assigned to seven dietary treatments: the s diet as in Exp. I, or this diet supplemented with thymol in o formulations (on celite, on alphacel or microencapsulated) at doses 2000 mg kg^{-1}. At 11/12 days post-weaning piglets were euthanised, from stomach, proximal and distal small intestine were sampled for gical and biochemical analysis. Small intestinal tissue was sample morphological determinations. In none of the experiments or sectio



Journal of Food Protection, Vol. 75, No. 4, 2012, Pages 758–761
doi:10.4315/0362-028X.JFP-11-390

Research Note

Effect of Thymol or Diphenyliodonium Chloride on Performance, Gut Fermentation Characteristics, and _Campylobacter_ Colonization in Growing Swine†‡

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MS 11-390: Received 22 August 2011/Accepted 14 December 2011

ABSTRACT

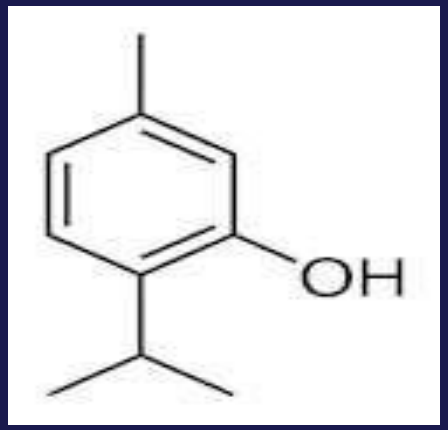
Food producing animals can be reservoirs of _Campylobacter_, a leading bacterial cause of human foodborne illness. _Campylobacter_ spp. utilize amino acids as major carbon and energy substrates, a process that can be inhibited by thymol and diphenyliodonium chloride (DIC). To determine the effect of these potential additives on feed intake, live weight gain, and gut _Campylobacter_ levels, growing pigs were fed standard grower diets supplemented with or without 0.0067 or 0.0201% thymol or

The work in this bottom paper was funded in part by the National Pork Board.

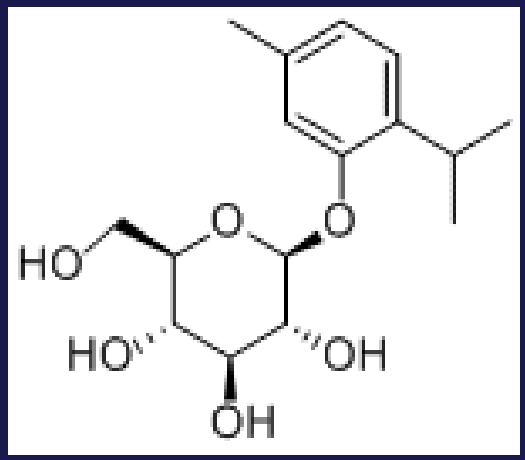
So bypass technologies are needed to deliver thymol to the lower gut

So we thought we could perhaps protect thymol from rapid sbsoption by conjugating to glucose with a β-glycosidic bond

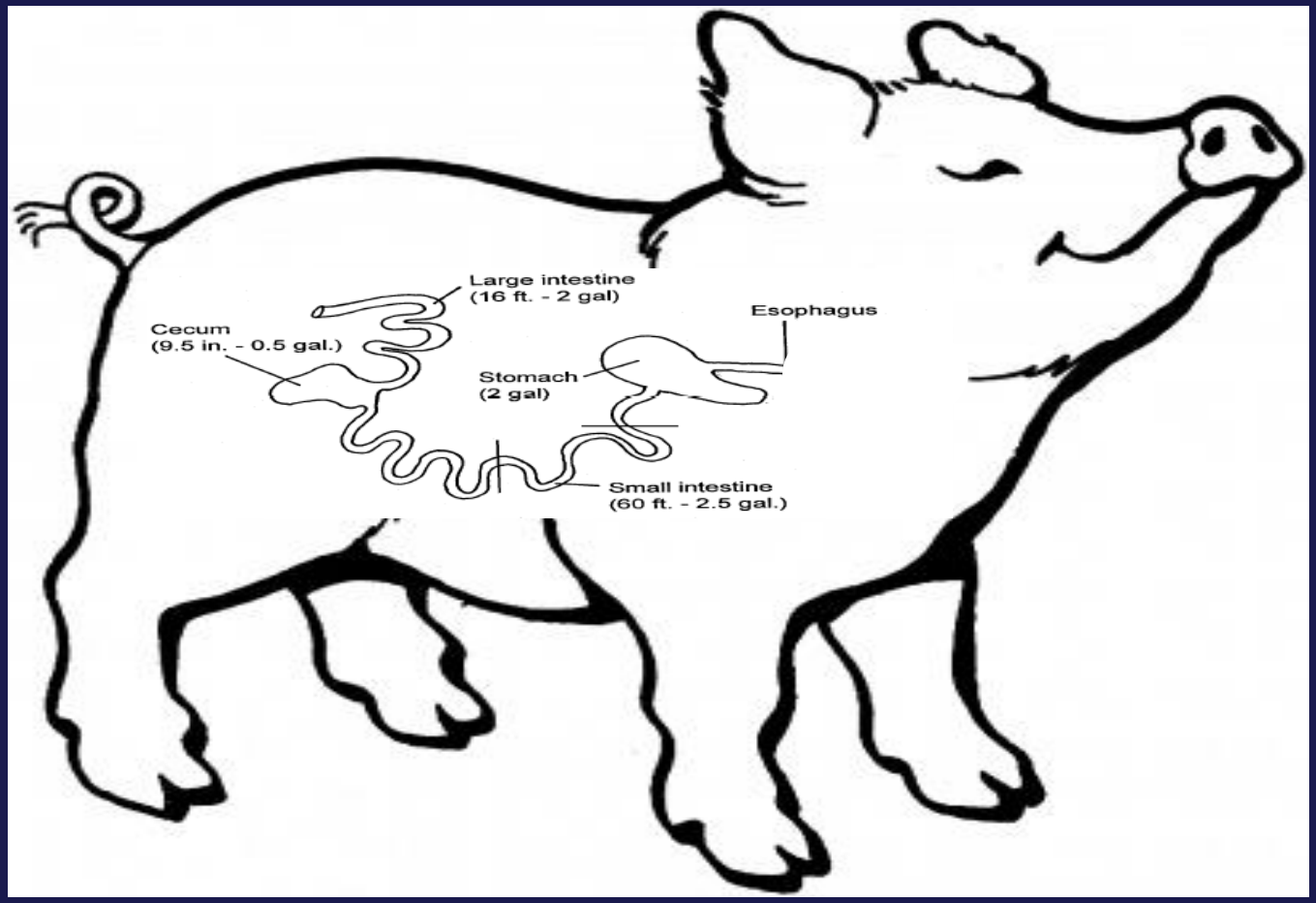
Thymol



Thymol-β-D-glucopyranoside (β-D-thymol)



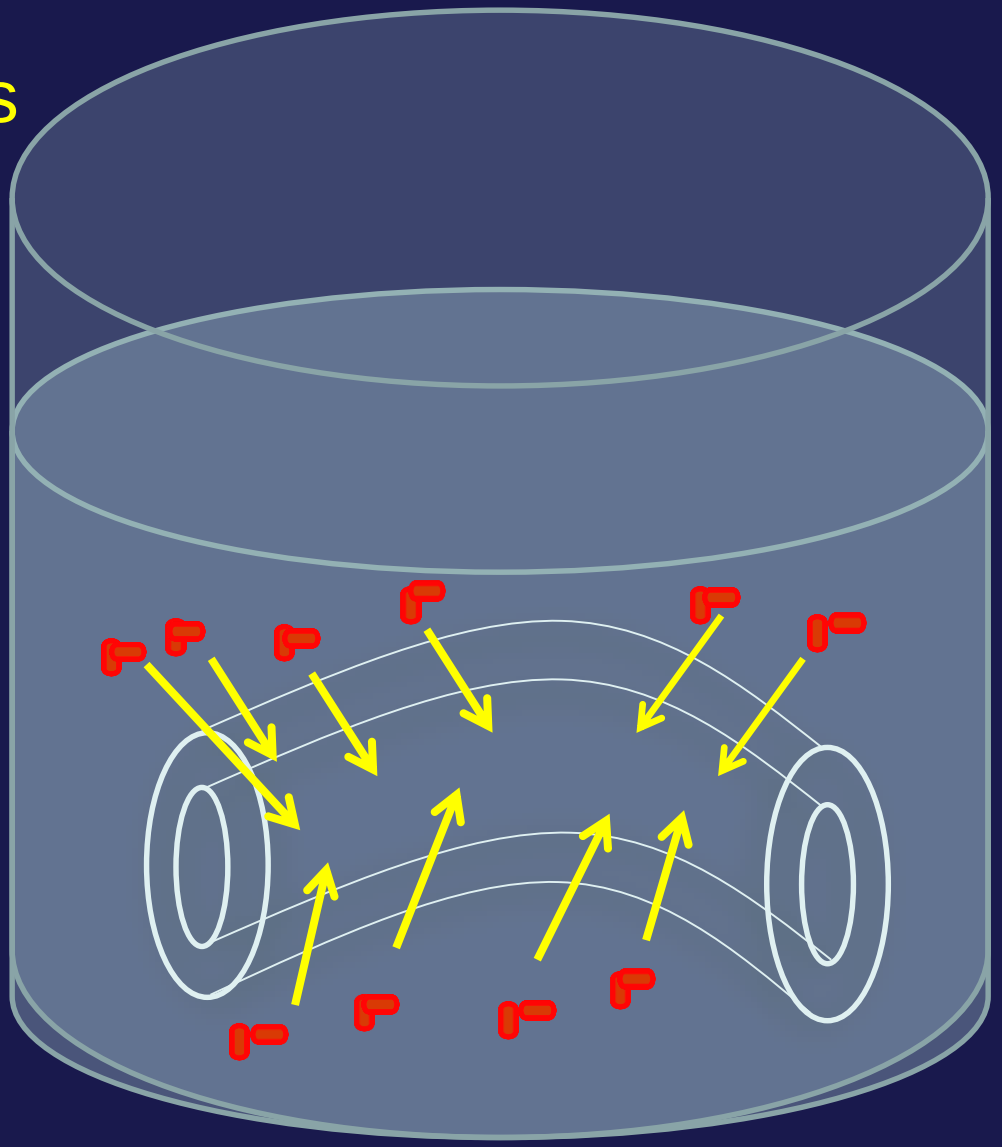
Thymol-β-D-glucopyranoside (β-D-thymol) as a potential bypass additive



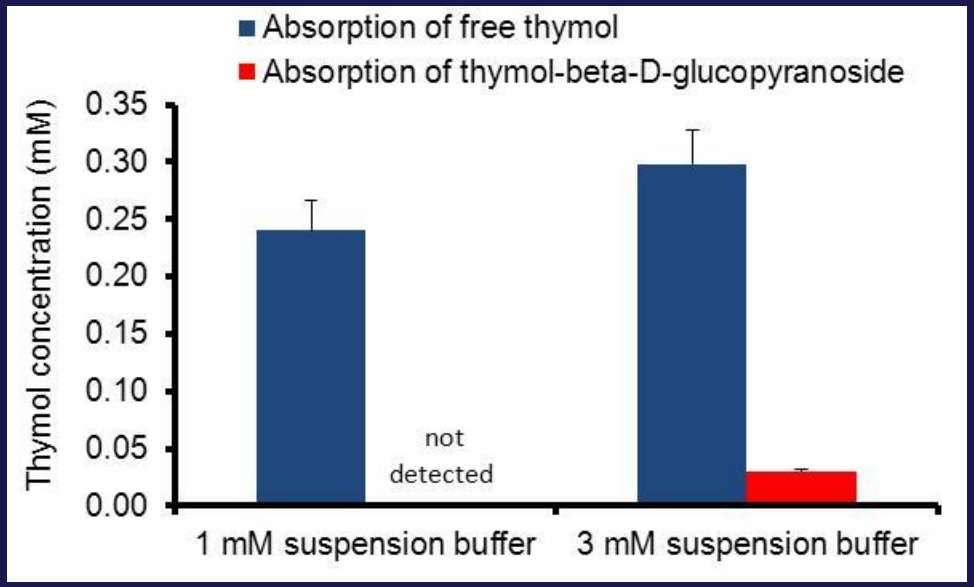
Material Studio by Accelrys Inc provided by the Laboratory for Molecular Simulation at Texas A&M University.

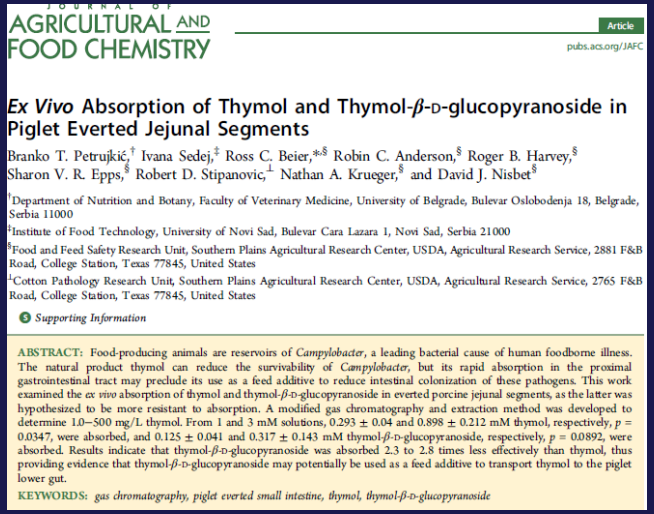
Everted jejunal segments to investigate absorption

- Turn jejunal segments inside out and tie off.
- So measures absorption of thymol or thymol-β-D-glucopyranoside from buffer to inside of tied-off segments.



Thymol-β-D-glucopyranoside was translocated across everted porcine jejunal segments less efficiently than free thymol





JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

Article

pubs.acs.org/JAFC

***Ex Vivo* Absorption of Thymol and Thymol-β-D-glucopyranoside in Piglet Everted Jejunal Segments**

Branko T. Petrujkić,[†] Ivana Sedej,[‡] Ross C. Beier,[*,§] Robin C. Anderson,[§] Roger B. Harvey,[§] Sharon V. R. Epps,[§] Robert D. Stipanovic,[⊥] Nathan A. Krueger,[§] and David J. Nisbet[§]

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Supporting Information

ABSTRACT: Food-producing animals are reservoirs of *Campylobacter*, a leading bacterial cause of human foodborne illness. The natural product thymol can reduce the survivability of *Campylobacter*, but its rapid absorption in the proximal gastrointestinal tract may preclude its use as a feed additive to reduce intestinal colonization of these pathogens. This work examined the *ex vivo* absorption of thymol and thymol-β-D-glucopyranoside in everted porcine jejunal segments, as the latter was hypothesized to be more resistant to absorption. A modified gas chromatography and extraction method was developed to determine 10−500 mg/L thymol. From 1 and 3 mM solutions, 0.293 ± 0.04 and 0.898 ± 0.212 mM thymol, respectively, $p = 0.0347$, were absorbed, and 0.125 ± 0.041 and 0.317 ± 0.143 mM thymol-β-D-glucopyranoside, respectively, $p = 0.0892$, were absorbed. Results indicate that thymol-β-D-glucopyranoside was absorbed 2.3 to 2.8 times less effectively than thymol, thus providing evidence that thymol-β-D-glucopyranoside may potentially be used as a feed additive to transport thymol to the piglet lower gut.

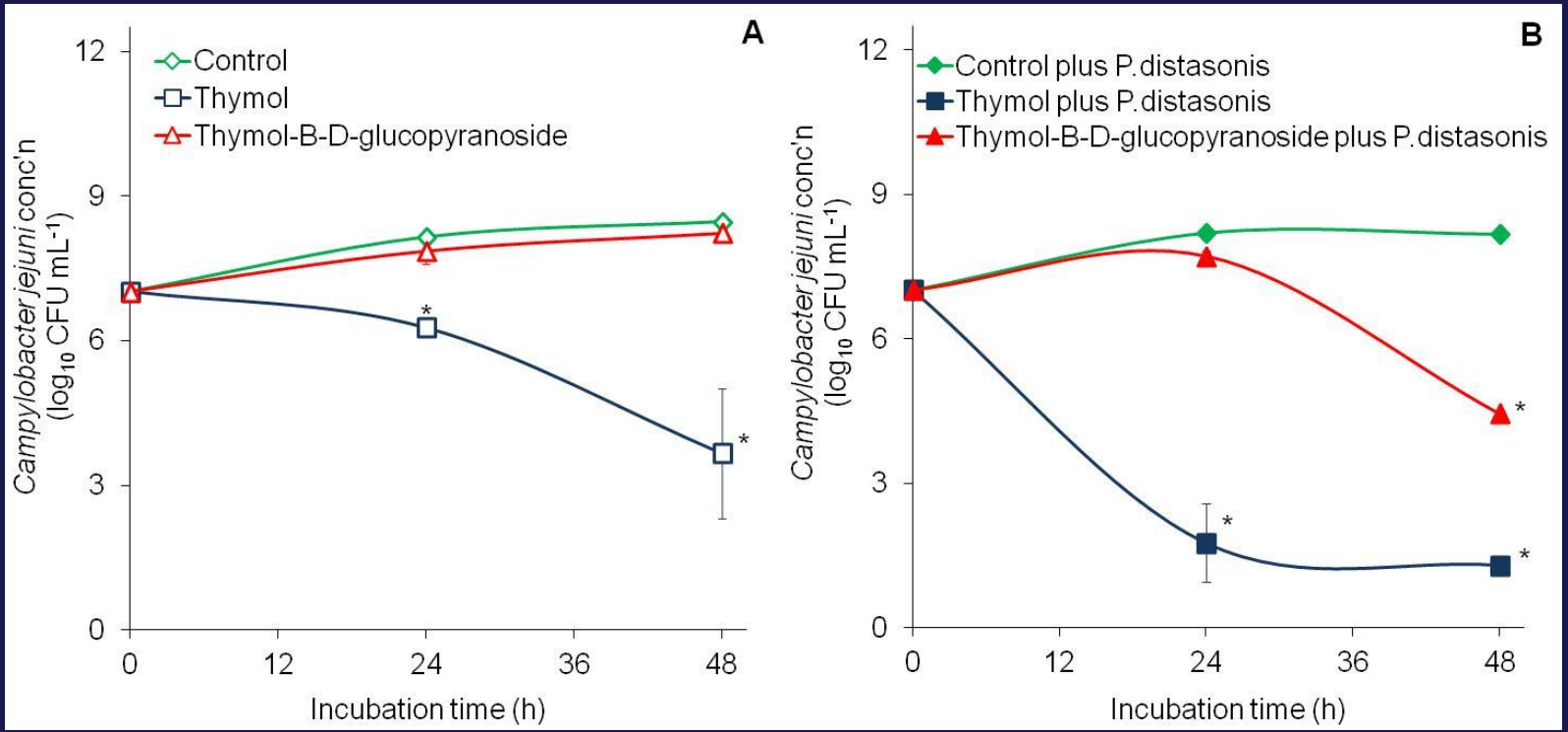
KEYWORDS: *gas chromatography, piglet everted small intestine, thymol, thymol-β-D-glucopyranoside*

The work in this paper was funded in part by the National Pork Board.

These results indicate that the conjugated form of thymol may resist absorption in the proximal alimentary tract and thus pass intact to the lower gut where it can be activated (hydrolyzed) by microbial expressed β-glycosidase

Petrujkic et al. 2014. J. Agric. Food Chem.

Thymol-β-D-glucopyranoside has little bactericidal activity unless activated by β-glycosidase expressing bacteria

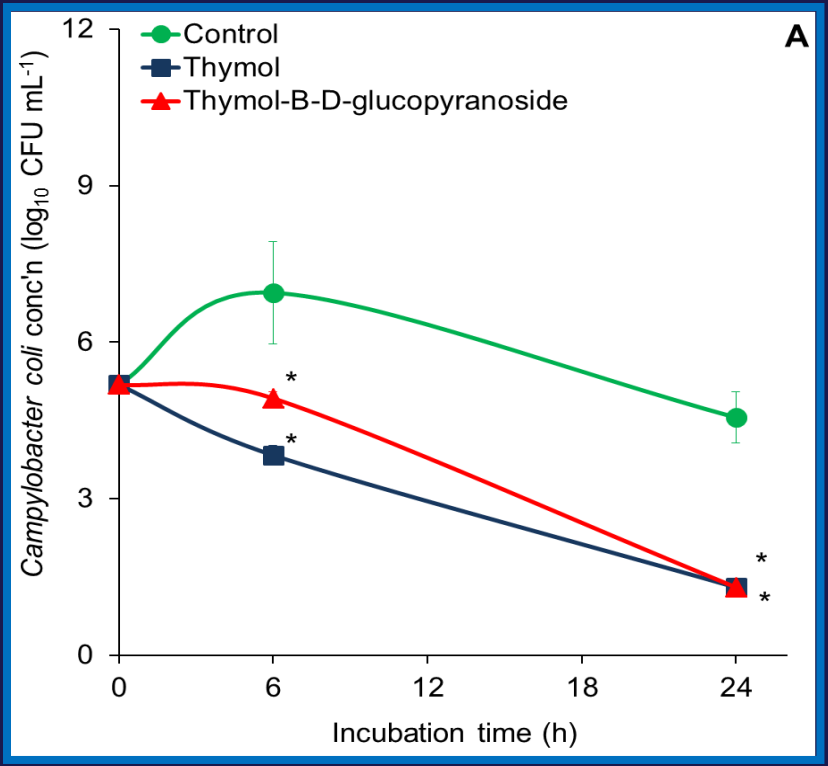


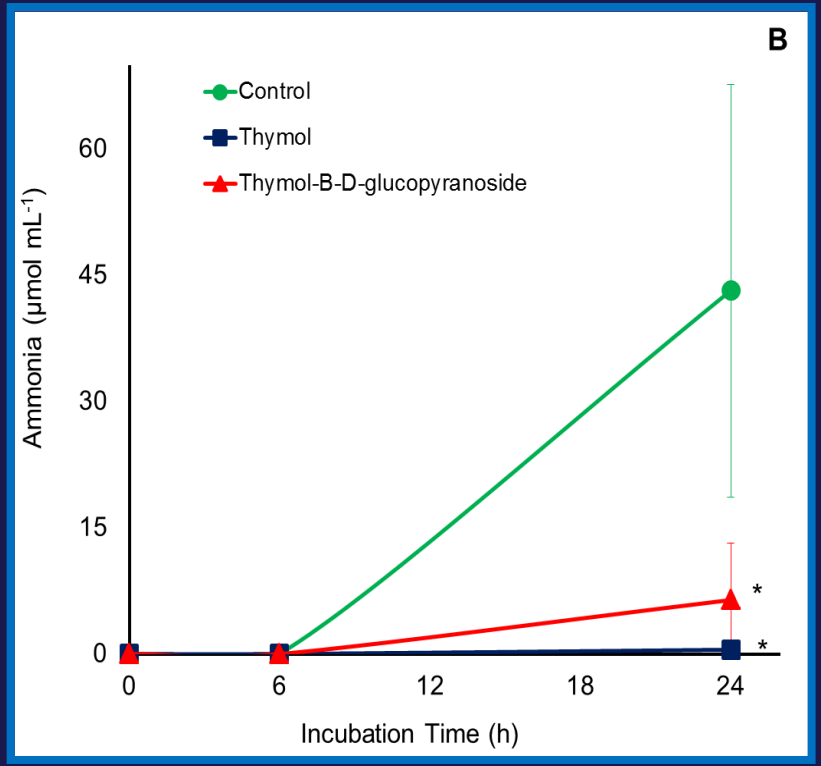
-In pure culture, viable cell counts of *Campylobacter jejuni* were reduced in cultures treated with thymol but not in cultures treated with thymol-*β*-D-glucopyranoside (Fig. A).

-Conversely, when co-cultured with a *β*-glycosidase expressing *Parabacteroides distasonis* (Fig. B), growth of *Campylobacter jejuni* was inhibited in cultures treated with thymol and in cultures treated with thymol-*β*-D-glucopyranoside.

This work was funded in part by the National Pork Board.

Mixed populations of pig gut microbes also possess sufficient *β*-glycosidase activity to activate (hydrolyze) the conjugated form of thymol





These results indicate that there is significant ammonia inhibition with thymol and thymol-β-D-glucopyranoside.

This work was funded in part by the National Pork Board.

Results from two separate animal studies were not particularly encouraging

Table 2. Effect of oral beta-D-thymol treatment on gut NN-resistant *Salmonella* Typhimurium and generic *E. coli* in weaned swine.

	Beta-D-thymol treatment[a] (mg/kg live body weight)			P values		
	None	6	12	Linear	Quadratic	SEM
	Log_{10} CFU/g gut contents					
Salmonella Typhimurium						
Cecal	3.52	3.26	2.37	0.0287	0.3545	0.533
Rectal	3.57	2.98	2.82	0.4567	0.9988	0.501
Escherichia coli						
Cecal	6.63	6.93	7.15	0.5155	0.8281	0.267
Rectal	6.83	6.88	7.19	0.9836	0.1327	0.282

[a]6 pigs per treatment were twice-treated via oral gavage (approximately 5 hours apart) and euthanized 12 h after receiving last treatment.

Table 3. Effect of oral beta-D-thymol treatment on gut NN-resistant *Salmonella* Typhimurium and generic *E. coli* and *Campylobacter* species in weaned swine.

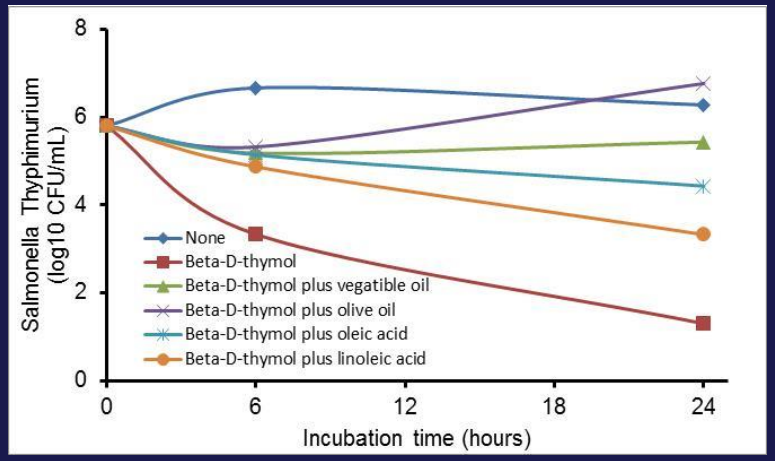
	Beta-D-thymol treatment[a]								
	Treatment level (mg/kg live body weight)			Hours since last administration		Main effects			
	None	17	51	16	24	Treatment	Time	Interaction	SEM
Salmonella Typhimurium									
Cecal	2.70	2.77	2.64	2.20	3.21	0.9604	0.0290	0.8787	0.5396
Rectal	2.10	2.10	1.37	2.00	1.72	0.2696	0.4545	0.7555	0.4818
Escherichia coli									
Cecal	5.29	5.88	5.37	5.26	5.76	0.2308	0.2484	0.8594	0.5496
Rectal	4.73[bc]	5.54[b]	4.35[c]	5.01	4.73	0.0100	0.3822	0.6097	0.3977
Campylobacter species									
Cecal	4.04	4.13	3.52	3.67	4.13	0.2144	0.1232	0.2654	0.3677
Rectal	3.48	3.76	3.57	3.23	3.98	0.8103	0.0150	0.3274	0.3528

[a]*n* = 6, 6 and 6 pigs for 0, 17 and 51 mg/kg live body weight per day at 16 h post treatment and 6, 5 and 6 for 0, 17 and 51 mg/kg live body weight per day at 24 h post treatment, respectively.

This work was funded in part by the National Pork Board.

Investigating three hypotheses as to why the β-D-thymol did not work

The first hypothesis is that thymol may be sequestered within in the gut environment such as in fat complexes or within microbial cells



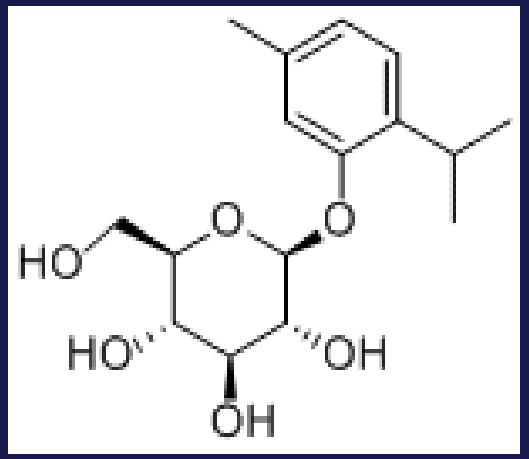
Evidence in support of this hypothesis is that lipids markedly decrease the bactericidal activity of free thymol.

Presently looking at ways to potentially overcome hurdle by adding emulsifiers to break up fats or extra calcium which might bind to the fat.

This work was funded in part by the National Pork Board.

Second hypotheses, β-D-thymol may still be to small and even though absorbed more slowly than free thymol it not make it all the way to the cecum and large intestine

We are looking at making conjugates with larger side chains and more binding sites for thymol to see if this may promote passage to the lower gut



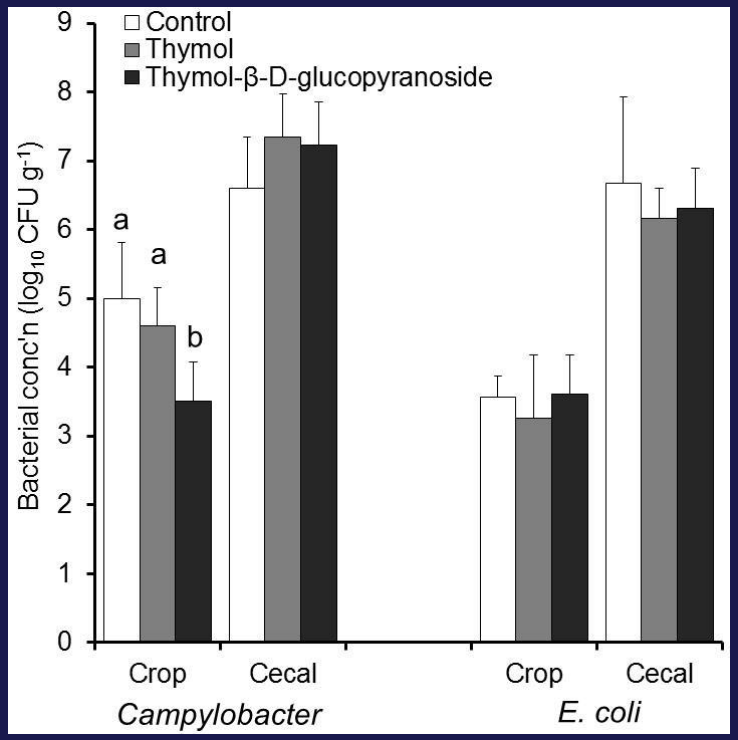
Thymol-β-D-glucopyranoside (β-D-thymol)

This work was funded in part by the National Pork Board.

The third hypotheses is that the β-D-thymol hydrolyzing activity may be too rapid or too slow to achieve optimal liberation of free thymol

Evidence in support of this hypothesis is that the thymol is liberated very rapidly in the poultry crop which has a relatively shorter retention time than the pig gut.

Potential ways to overcome this may be to employ additional encapsulation or protection technologies.

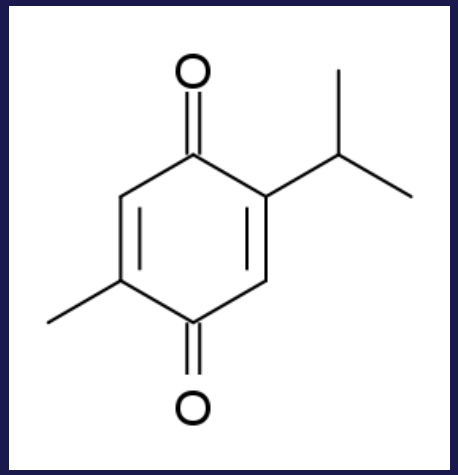


Another approach we are investigating is to use natural sources of thymol as these may contain thymol in naturally-conjugated or protected forms

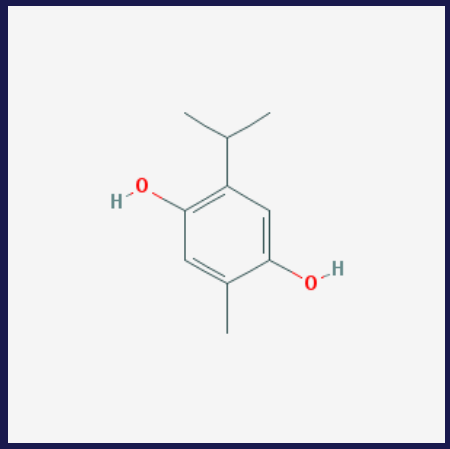
Nigella sativa
Black cumin seed

https://en.wikipedia.org/wiki/Nigella_sativa

- A natural source of thymol derivatives as well as a number of other phytochemicals



Thymoquinone

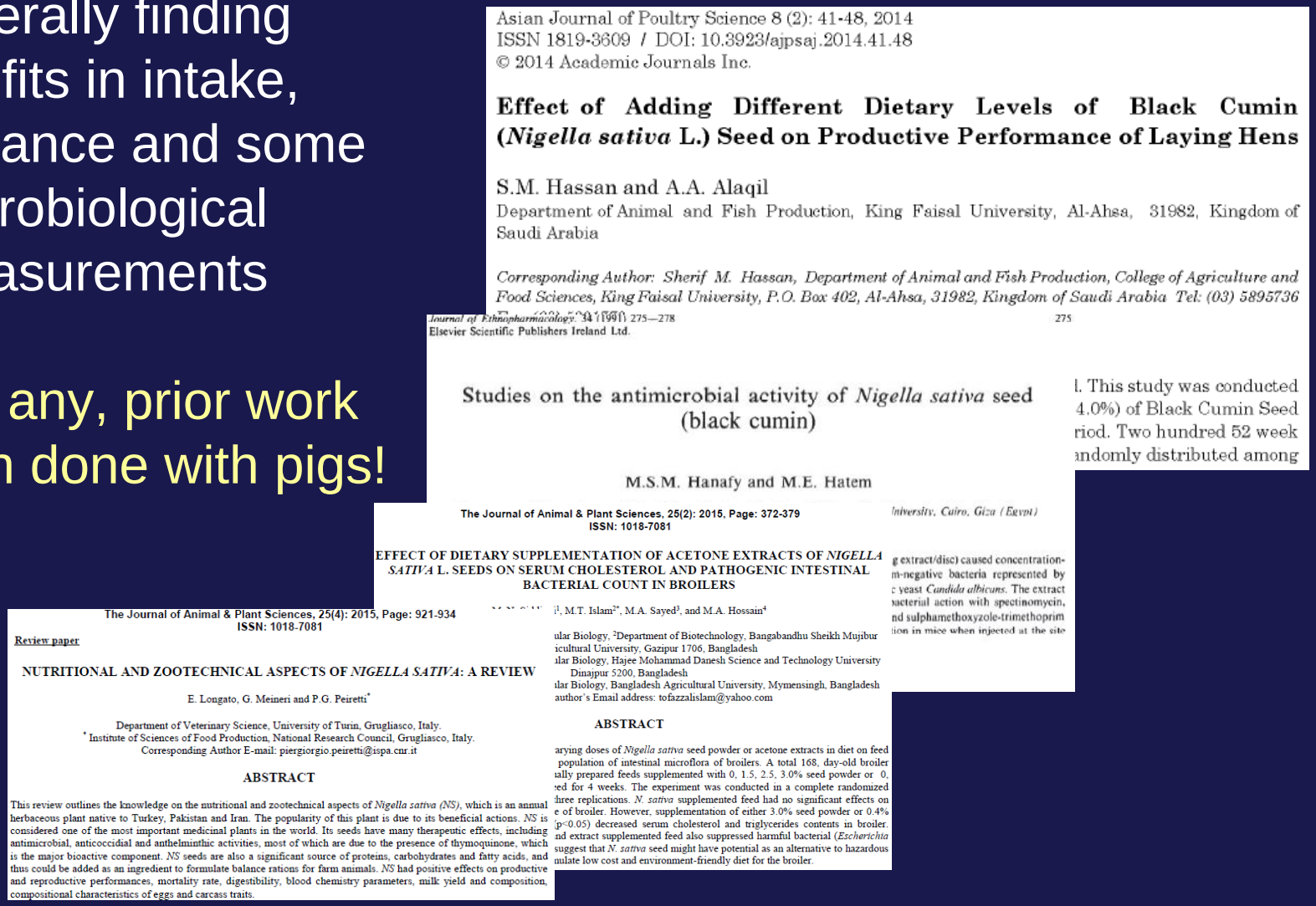


Thymohydroquinone

Investigated in the Middle East as a feed additive poultry and small ruminants

Generally finding benefits in intake, performance and some microbiological measurements

Little, if any, prior work has been done with pigs!



Asian Journal of Poultry Science 8 (2): 41-48, 2014
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Effect of Adding Different Dietary Levels of Black Cumin (*Nigella sativa* L.) Seed on Productive Performance of Laying Hens

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Journal of Ethnopharmacology, 34 (1991) 275—278 275
Elsevier Scientific Publishers Ireland Ltd.

Studies on the antimicrobial activity of *Nigella sativa* seed (black cumin)

M.S.M. Hanafy and M.E. Hatem

l. This study was conducted
4.0%) of Black Cumin Seed
riod. Two hundred 52 week
ndomly distributed among

The Journal of Animal & Plant Sciences, 25(2): 2015, Page: 372-379
ISSN: 1018-7081

EFFECT OF DIETARY SUPPLEMENTATION OF ACETONE EXTRACTS OF *NIGELLA SATIVA* L. SEEDS ON SERUM CHOLESTEROL AND PATHOGENIC INTESTINAL BACTERIAL COUNT IN BROILERS

g extract/disc) caused concentration-
m-negative bacteria represented by
e yeast *Candida albicans*. The extract
acterial action with spectinomycin,
nd sulphamethoxyzole-trimethoprim
ion in mice when injected at the site

ABSTRACT

arying doses of *Nigella sativa* seed powder or acetone extracts in diet on feed
population of intestinal microflora of broilers. A total 168, day-old broiler
ially prepared feeds supplemented with 0, 1.5, 2.5, 3.0% seed powder or 0,
ed for 4 weeks. The experiment was conducted in a complete randomized
three replications. *N. sativa* supplemented feed had no significant effects on
e of broiler. However, supplementation of either 3.0% seed powder or 0.4%
($p<0.05$) decreased serum cholesterol and triglycerides contents in broiler.
nd extract supplemented feed also suppressed harmful bacterial (*Escherichia*
suggest that *N. sativa* seed might have potential as an alternative to hazardous
mulate low cost and environment-friendly diet for the broiler.

The Journal of Animal & Plant Sciences, 25(4): 2015, Page: 921-934
ISSN: 1018-7081

Review paper

NUTRITIONAL AND ZOOTECHNICAL ASPECTS OF *NIGELLA SATIVA*: A REVIEW

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ABSTRACT

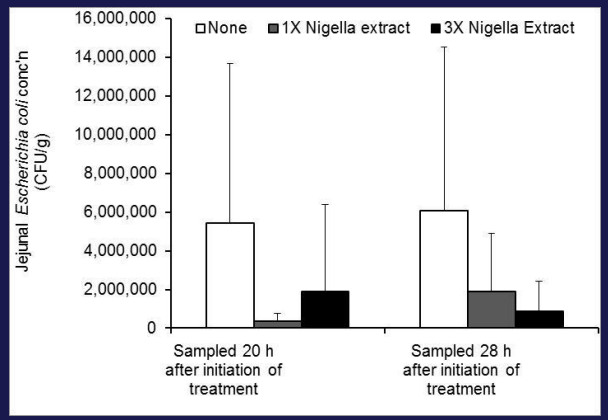
This review outlines the knowledge on the nutritional and zootechnical aspects of *Nigella sativa (NS)*, which is an annual herbaceous plant native to Turkey, Pakistan and Iran. The popularity of this plant is due to its beneficial actions. *NS* is considered one of the most important medicinal plants in the world. Its seeds have many therapeutic effects, including antimicrobial, anticoccidial and anthelminthic activities, most of which are due to the presence of thymoquinone, which is the major bioactive component. *NS* seeds are also a significant source of proteins, carbohydrates and fatty acids, and thus could be added as an ingredient to formulate balance rations for farm animals. *NS* had positive effects on productive and reproductive performances, mortality rate, digestibility, blood chemistry parameters, milk yield and composition, compositional characteristics of eggs and carcass traits.

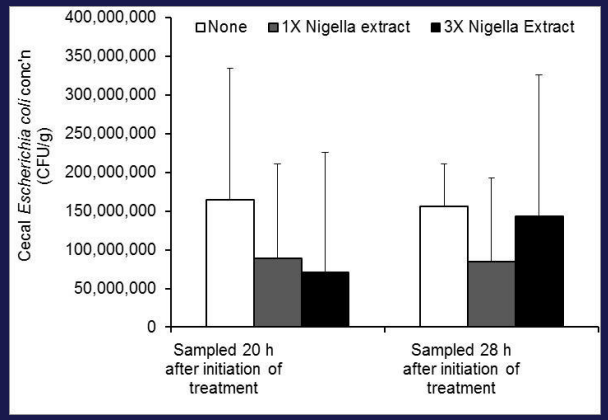
Results from just completed studies in our laboratory

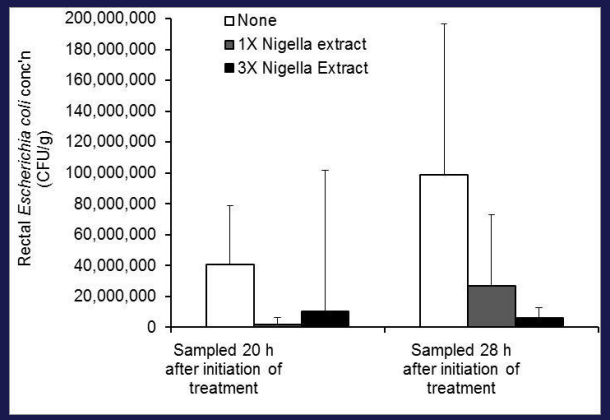
Bench top studies confirmed dose-dependent antimicrobial activity against *E. coli, Campylobacter* and *Salmonella*

- Higher doses needed for *Salmonella*

Preliminary animal study with nursery pigs administered Nigella extract via oral gavage provided supporting evidence of a positive effect against *E. coli*



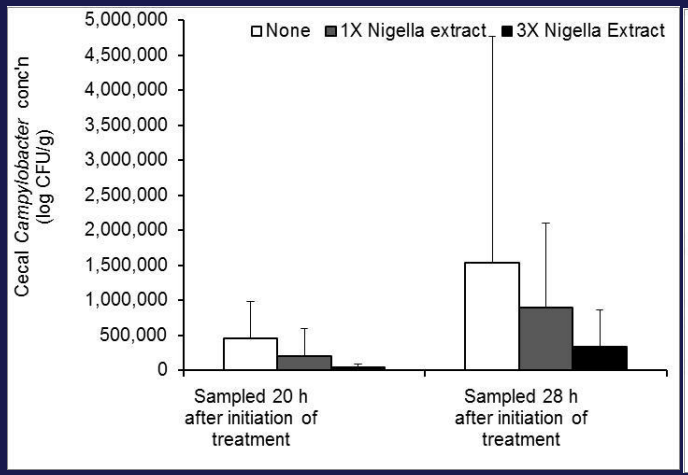


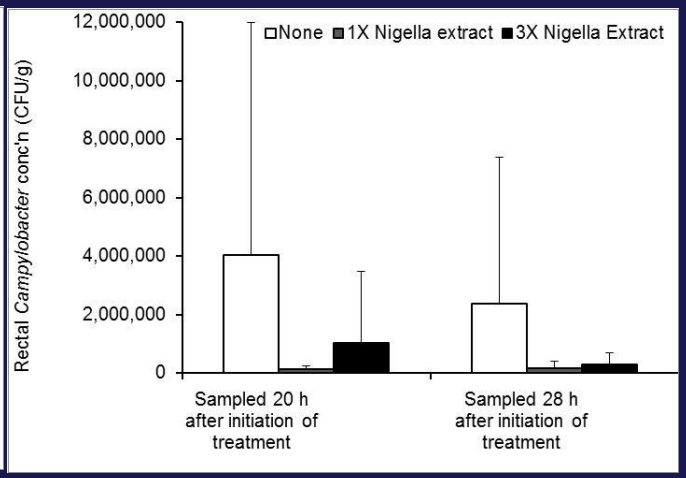


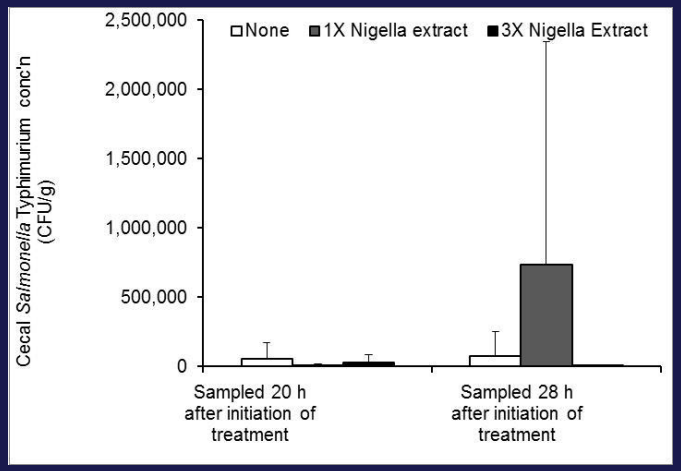
1X dose in gavage study is equivalent to a dose that would be expected if mixed 0.15% with diet DM

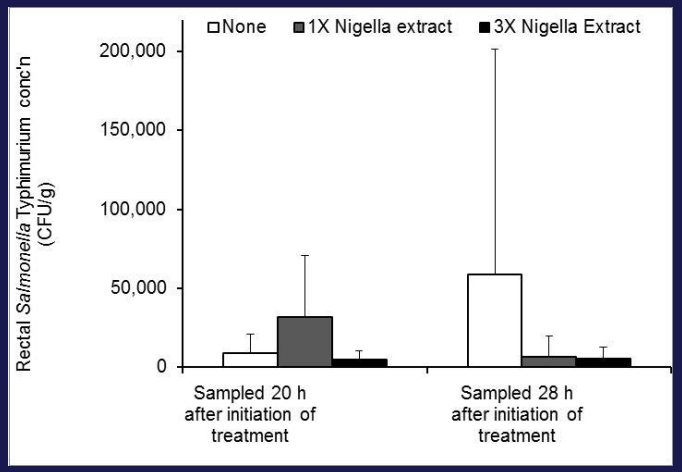
This work was funded in part by the National Pork Board.

Evidence for positive effects against *Campylobacter* were also observed









But not against *Salmonella* at the doses tested

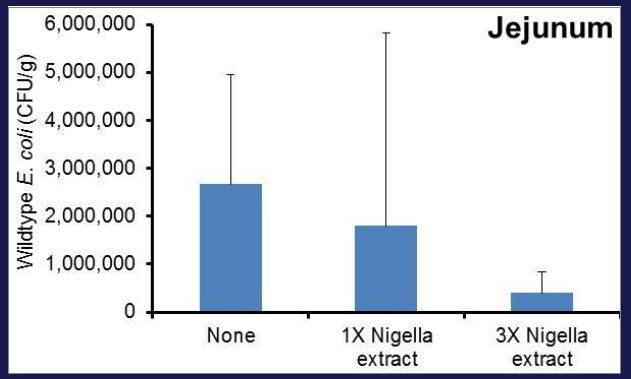
1X dose equivalent to 0.15% diet DM

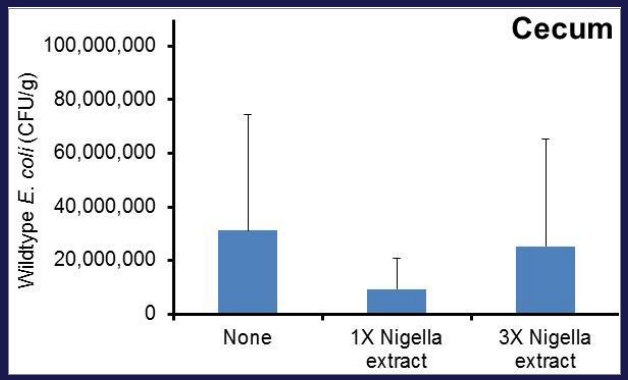
Negative effects against total culturable anaerobes (good fermenting bacteria) were not observed.

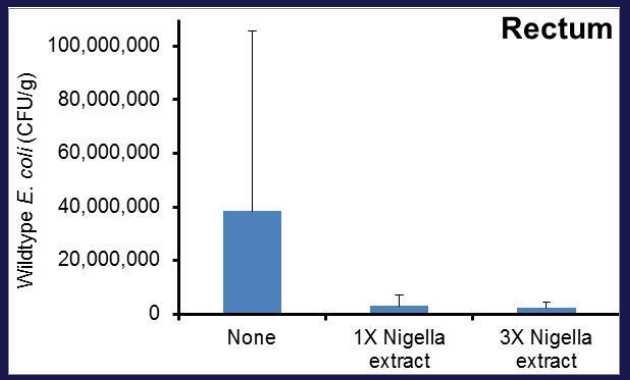
This work was funded in part by the National Pork Board.

Results from a follow up animal feeding study with weaned pigs

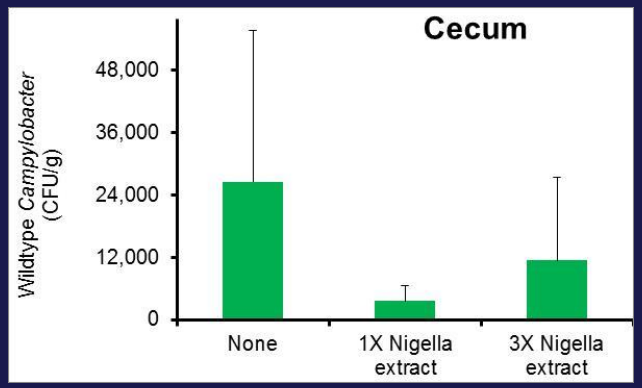
Again showed evidence for a positive treatment effect in reducing gut concentrations of wildtype *E. coli and Campylobacter*

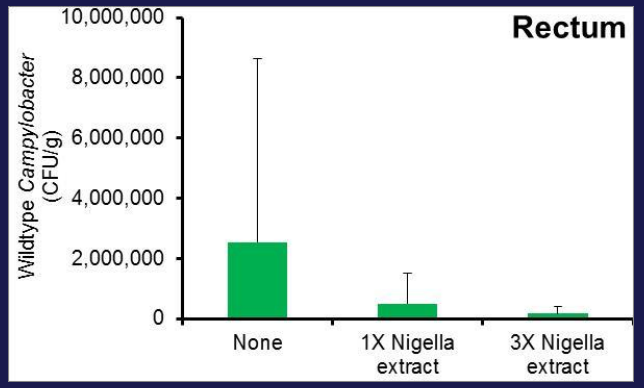






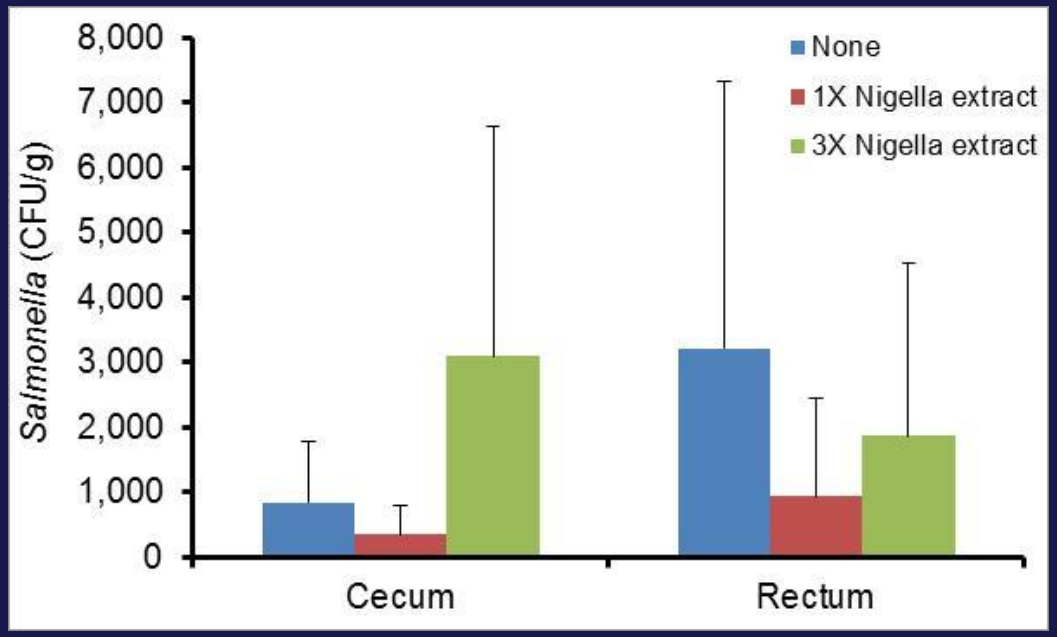
1X dose in feeding study
= 0.15% diet DM





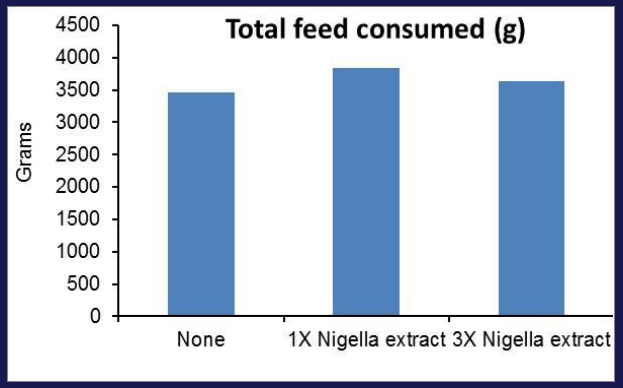
This work was funded in part by the National Pork Board.

But not against our challenge strain of *Salmonella* Typhimurium

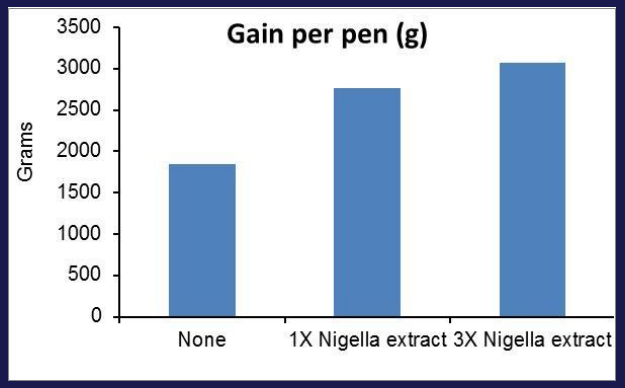


1X dose in feeding study
= 0.15% diet DM

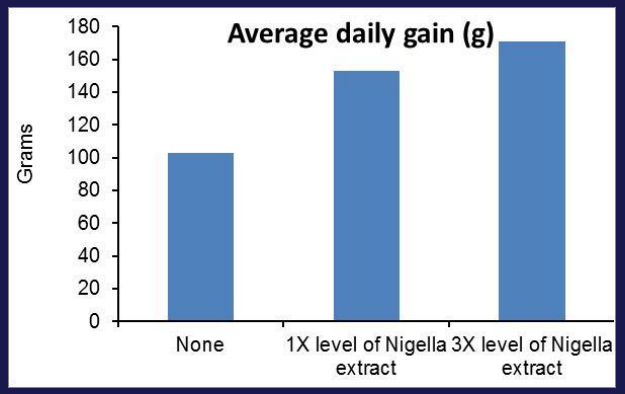
Positive effects of feeding Nigella extract were observed on piglet performance



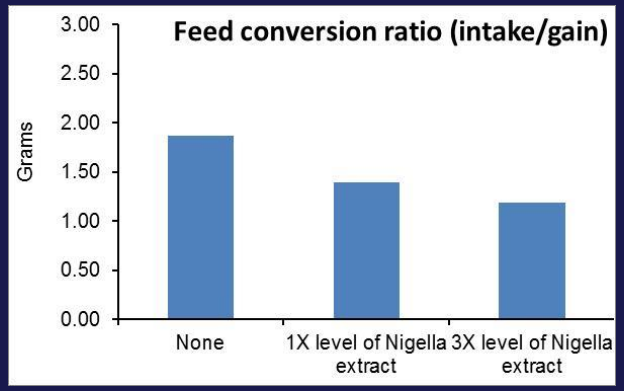
Treated pigs ate slightly more feed



Treated pigs gained more weight



Treated pigs had higher average daily gain



Treated pigs had a better feed conversion

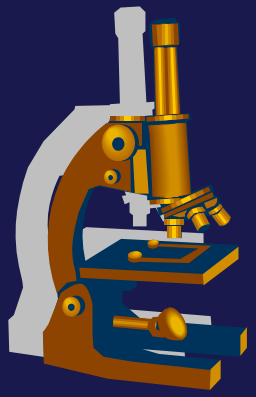
1X dose in feeding study = 0.15% diet DM

This work was funded in part by the National Pork Board.

Summary

- Essential oil compounds have demonstrated antimicrobial activity but their rapid adsorption and high solubility in lipid limits their efficacy in animals
- Attempts to protect free thymol using glucose conjugates have not overcome these limitations
- Use of extracts of Nigella sativa have shown promise in reducing *E. coli* and *Campylobacter* but not *Salmonella*
  - Greater range of concentrations and terminal application may be needed to achieve efficacious reductions in *Salmonella*
- Positive effects of Nigella extracts on animal performance may allow recovery of costs of use
  - Longer term studies with different extract preparations are warranted to more clearly define potential benefits

Acknowledge support from the National Pork Board, Texas AgricLife
Norman Borlaug Institute for International Agriculture



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