Practical implications of plant-derived antimicrobials in poultry diets for the control of *Salmonella* Enteritidis¹

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Primary Audience: Researchers, Poultry Producers, Nutritionists, Veterinarians

**SUMMARY**

Several plant-derived antimicrobials have been tested under laboratory or research farm conditions and have been shown to be effective in reducing the colonization and shedding of *Salmonella* Enteritidis from laying hens and broiler chickens when added to the feed. How well these particular compounds or essential oils work under commercial conditions is yet to be determined. Some of the practical implications of using these compounds in commercial poultry feed or diets are discussed in this paper. In general, an ample supply of many of these compounds exist, they are relatively easily mixed with other feed ingredients, and are effective at relatively small amounts. The cost of adding to the feed is still a variable and the total economic effect can only be estimated at this point.

**Key words:** *Salmonella* Enteritidis, egg, plant-derived molecule, essential oil

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is more of a gut colonization issue, cell clearance of the pathogen is not actually attributed to antibodies but to T-cells, which is why the live vaccines are more effective [1]. With consumer demand for organically produced foods growing more than 20% a year for over a decade in the United States [8, 9], increased interest has been observed in the use of more natural approaches to controlling Salmonella Enteritidis in poultry.

Various plant-derived compounds have been used by humans for centuries for ointments, salves, insecticides, perfumes, and for their healing powers. Research over the past 100 yr has revealed that many plants produce a large number of active compounds, most of which act as a defense mechanism against predation by pathogenic microorganisms and insects. Several plant compounds have been used in dietary constituents and as active components in several herbal and traditional medicines [10]. In recent years, the use of natural compounds has gained attention due to increasing concerns over the safety of synthetic chemicals [11, 12] and emerging antibiotic resistance in bacteria [12]. The antimicrobial properties of several plant-derived essential oils have been previously reported, and a variety of ingredients in these oils have been identified [13–15]. Among the various plant-derived antimicrobials (PDA), trans-cinnamaldehyde (TC) is a major ingredient in cinnamon (Cinnamomum zeylandicum). Carvacrol (CR) and thymol (THY) are extracted from oregano oil, which is obtained from Origanum glandulosum, whereas eugenol (EUG) is a component of clove oil (Eugenia caryophyllis). These aforementioned PDA are reported to be effective against several gram-negative and -positive bacteria [16–18] and are classified as generally recognized as safe by the Food and Drug Administration [19–22]. Our laboratory previously reported that these molecules were effective in killing Salmonella Enteritidis in vitro [23, 24] and in broiler chickens in vivo [25–27] and inactivating the pathogen on shell eggs [28, 29].

**USING PDA IN POULTRY DIETS**

To date, researchers have shown that certain PDA are effective in reducing Salmonella in poultry under experimental conditions. However, several obstacles must be overcome before these compounds gain widespread commercial use. Some questions that need to be answered are:

1. What is the concentration that is needed in the feed, a sublethal, a minimum inhibitory, or a minimum bactericidal concentration?
2. Will birds consume feed supplemented with the PDA?
3. Will they mix easily in the feed?
4. Are these compounds available to meet the demand of the industry?
5. How much do they cost?
6. Will they affect the use of Salmonella vaccine?

**How Much of the PDA Is Needed in the Feed?**

The level of PDA in the feed depends on several factors, one of the most important being the concentration or dose of the PDA. To kill Salmonella it takes the minimum inhibitory or minimum bactericidal concentration, such as between 0.7 and 1% for caprylic acid (CA) [27], 0.5 to 0.75% for TC, and 0.75 to 1% for EUG [25]. However, using the sublethal dose of the PDA did reduce the virulence attributes of Salmonella Enteritidis in vitro. Further research to determine the effects of sublethal doses of PDA on Salmonella Enteritidis in vivo is needed before recommending these levels for commercial feeding. For example, the sublethal concentration of CA, TC, and EUG in vitro were 0.075, 0.0075, and 0.03%, respectively [27, 30, 31]. These levels would not kill any normal endogenous flora or cause any palatability issues. The latter approach may be more practical for commercialization purposes, given the economic factors under consideration.

**Will Birds Consume Feed Supplemented with PDA?**

Of all PDA tested in our laboratory, only EUG resulted in a reduced feed intake that affected overall bird weights; CA and TC did not adversely affect feed intake or BW of broilers [25–27].
Will the PDA Mix Easily in the Feed?

Caprylic acid is soluble in alcohol, chloroform, ether, petroleum ether, and acetonitrile, and thus can be mixed with liquid fats added to the diet. Sodium caprylate is a water-soluble form of CA and has been shown to be effective in reducing Salmonella Enteritidis in drinking water [28]. Caprylic acid is also soluble in mineral oil and was tested in our laboratory for use as an egg-surface sanitizer at a concentration of 3% and was found to be effective in reducing Salmonella Enteritidis [28].

Eugenol is a clear to pale yellow oily liquid extracted from clove oil, nutmeg, cinnamon, and bay leaf. It is slightly soluble in water and soluble in organic solvents. It can be mixed with alcohol or mineral oil or liquid fats and added to the diet. Thymol (also known as 2-isopropyl-5-methylphenol) is a natural monoterpene phenol derivative of cymene, \( C_{10}H_{14}O \), isomeric with CR, found in the oil of thyme. Thymus vulgaris (common thyme), and various other kinds of plants, generate a white crystalline substance of a pleasant aromatic odor and strong antiseptic properties when extracted. Thymol is only slightly soluble in water at neutral pH, but it is extremely soluble in alcohols and other organic solvents. Carvacrol, the isomer of TH, is present in the essential oil of Origanum vulgare (oregano), oil of thyme, and oil obtained from peppermint and wild bergamot. The essential oil of thyme subspecies contains between 5 and 75% CR, whereas Satureja (savory) subspecies have content between 1 and 45%. Origanum majorana (marjoram) and Dittany of Crete are rich in CR, 50 and 80%, respectively. It is soluble in ethanol, diethyl ether, carbon tetrachloride, acetone, and lipids.

Cinnamaldehyde is the pytophenolic organic compound that gives cinnamon its flavor and odor. This pale yellow, viscous liquid occurs naturally in the bark of cinnamon trees and other species of the genus Cinnamomum. The essential oil of cinnamon bark is about 90% cinnamaldehyde. As an oil, it is easily soluble in acetone or ether and is miscible in alcohol and oils. Given these observations, we have to ascertain the stability of these products in poultry feeds, if they can withstand the pelleting process, and how long the products will remain viable in stored feed. These questions are the subjects of ongoing and future research.

Are PDA Available in Quantities Required by the Poultry Industry?

Reports on the current commercial layer industry in the United States indicates 292.4 million laying hens on feed [32]. If we assume an average of 109 g of feed/d per bird as a conservative estimate of total feed consumption, 31.9 million kg of feed would be consumed per day, or about 11.61 million t of feed per year. If PDA were fed at the sublethal levels, that would amount to 23,873, 2,387, 9,549, 2,387, and 2,387 kg/d or 8,713.81, 871.38, 763.98, 871.38, and 871.38 t/yr, respectively, for CA, TC, EUG, THY, and CR.

According to the USDA, the estimated total world production of coconut oil (from which CA is obtained) for 2013 is about 3,692 t, and the United States’ supply is about 587,000 t; so feeding poultry would amount to about 1.4% of the United States’ supply [33]. World production of cinnamon in 2011 was 197,468 t, according to the latest data from FAOSTAT [34]; thus, the poultry industry would use about 22% of world production.

The United States produces various herbs domestically, mostly in California. It is estimated that total domestic production of all herbs is now approximately 2,250 t. No statistics are available for each herb; however, the estimated domestic production was obtained from the American Spice Trade Association [35].

Eugenol is mainly produced from cloves and about 97,890 t was produced in 2011 [34]. According to the FAO, Indonesia produced around 70% of world clove oil in 2005, followed by Madagascar, with around 12%. Tanzania and the Comoros followed, with a share of 10% and 2.4%, respectively. The annual world trade of clove oil averaged 50,000 t during the period from 2000 to 2005. About 85% of clove oil is EUG, so the poultry industry would use about 8% of the clove oil in the world.

Many varieties of oregano exist; however, the 2 major varieties used in commerce today are Mediterranean (from Turkey) and Mexican. The United States imports about 7,711 t of oregano each year. It is not known how much thyme
is imported to the United States; however, about 90% of the thyme oil in world trade is produced in Spain. Oregano and thyme vary in their oil production, but yield is only 0.5 to 0.6%.

Although these estimates show that the United States can be supplied with many of these essential oils, the United States could not be supplied with enough THY for the entire industry at this point. However, the primary target for these products would be organic and other alternative production systems, which do not use antibiotics and are looking for more natural treatments.

**What Are the Costs of These PDA?**

As for most ingredients, the costs are not fixed and generally go down with volume purchases. However some estimates from the Food and Agriculture Organization of the United Nations suggest that CA costs ~$7.68/kg in 181-kg quantities, clove oil ~$3.78/kg, CAR ~$48.40/kg, cinnamaldehyde ~$4.40/kg, and THY ~$367.40/kg for conventional and $484/kg for certified organic.

**Will PDA Affect Salmonella Vaccination Programs?**

Only anecdotal evidence is available at this point, but those using TC and CA have not seen any adverse effect on the vaccinated birds and have actually noted a positive effect on reducing *Salmonella* Enteritidis incidence on the farms. This is another area where research is needed to support the use of these PDA in commercial, vaccinated birds. As stated earlier, vaccinations, biosecurity, and use of other methods, including PDA are all tools that should be used for control of *Salmonella*.

**CONCLUSIONS AND APPLICATIONS**

1. Feeding PDA, such as TC, CR, THY, EUG, or CA, may be used in conjunction with other control methods in an overall *Salmonella*-control program.

2. Further study needs to be undertaken to determine the stability and effectiveness of these compounds in commercial poultry feed, especially under adverse storage conditions.

3. It is expected that organic and other alternative production producers will be early adopters of the use of these compounds because of their generally recognized as safe status.

**REFERENCES AND NOTES**


