



RESEARCH ARTICLE

UPDATED Prevalence of antibiotic-resistant *E. coli* in retail chicken: comparing conventional, organic, kosher, and raised without antibiotics [version 2; referees: 2 approved, 1 approved with reservations]

Jack M Millman¹, Kara Waits², Heidi Grande², Ann R Marks¹, Jane C Marks³, Lance B Price⁴, Bruce A Hungate³

¹Horace Mann Bronx Campus, Bronx NY, 10471, USA

²Translational Genomics Research Institute, Flagstaff AZ, 86001, USA

³Department of Biological Sciences and Merriam-Powell Center for Environmental Research, Northern Arizona University, Flagstaff AZ, 86011, USA

⁴Department of Environmental and Occupational Health, George Washington University, Washington DC, 20037, USA

v2 First published: 11 Jul 2013, 2:155 (doi: 10.12688/f1000research.2-155.v1)
 Latest published: 02 Sep 2013, 2:155 (doi: 10.12688/f1000research.2-155.v2)

Abstract

Retail poultry products are known sources of antibiotic-resistant *Escherichia coli*, a major human health concern. Consumers have a range of choices for poultry, including conventional, organic, kosher, and raised without antibiotics (RWA) – designations that are perceived to indicate differences in quality and safety. However, whether these categories vary in the frequency of contamination with antibiotic-resistant *E. coli* is unknown. We examined the occurrence of antibiotic-resistant *E. coli* on raw chicken marketed as conventional, organic, kosher and RWA. From April – June 2012, we purchased 213 samples of raw chicken from 15 locations in the New York City metropolitan area. We screened *E. coli* isolates from each sample for resistance to 12 common antibiotics. Although the organic and RWA labels restrict the use of antibiotics, the frequency of antibiotic-resistant *E. coli* tended to be only slightly lower for RWA, and organic chicken was statistically indistinguishable from conventional products that have no restrictions. Kosher chicken had the highest frequency of antibiotic-resistant *E. coli*, nearly twice that of conventional products, a result that belies the historical roots of kosher as a means to ensure food safety. These results indicate that production methods influence the frequency of antibiotic-resistant *E. coli* on poultry products available to consumers. Future research to identify the specific practices that cause the high frequency of antibiotic-resistant *E. coli* in kosher chicken could promote efforts to reduce consumer exposure to this potential pathogen.

Open Peer Review

Referee Status:

	Invited Referees		
	1	2	3
version 2 published 02 Sep 2013		report	report
version 1 published 11 Jul 2013	report		report

- Marilyn Roberts**, University of Washington USA
- Irene Hanning**, University of Tennessee USA
- Katharina Stärk**, Royal Veterinary College UK

Discuss this article

Comments (0)

Corresponding authors: Lance B Price (lprice@gwu.edu), Bruce A Hungate (Bruce.Hungate@nau.edu)

How to cite this article: Millman JM, Waits K, Grande H *et al.* **Prevalence of antibiotic-resistant *E. coli* in retail chicken: comparing conventional, organic, kosher, and raised without antibiotics [version 2; referees: 2 approved, 1 approved with reservations]** *F1000Research* 2013, 2:155 (doi: [10.12688/f1000research.2-155.v2](https://doi.org/10.12688/f1000research.2-155.v2))

Copyright: © 2013 Millman JM *et al.* This is an open access article distributed under the terms of the [Creative Commons Attribution Licence](#), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. Data associated with the article are available under the terms of the [Creative Commons Zero "No rights reserved" data waiver](#) (CC0 1.0 Public domain dedication).

Grant information: This work was funded by the Merriam-Powell Center for Environmental Research and the Ecosystem Science & Society Center at Northern Arizona University.

The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing interests: No competing interests were disclosed.

First published: 11 Jul 2013, 2:155 (doi: [10.12688/f1000research.2-155.v1](https://doi.org/10.12688/f1000research.2-155.v1))

UPDATED Changes from Version 1

We thank the reviewers for their reports. We appreciate Dr. Hanning's comments and suggestions and have revised the manuscript to address each point raised.

The number of samples collected per brand is now indicated in the text. The number of brands per category is listed as "N" in Table 1.

We now state, by type of chicken collected, the percentages of isolates positive for some degree of antibiotic resistance in the fifth sentence of the Results section.

We have revised the first few sentences in the Discussion for clarity and to remove potentially inflammatory or unsupported claims. We have added several citations that provide support for our statements, and at the same time, we removed potentially inflammatory adjectives. We also add a statement about one specific estimate of the extent of antibiotic usage for growth promotion. We realize such estimates are controversial, but we feel that these provide important and useful context for readers in the field. For the second sentence in the original, we have followed Dr. Hanning's suggestion to modify the claim by changing "select" to "can select".

We appreciate the point that farm-to-farm variability could play a role in our results, and have added a sentence acknowledging this explicitly. Also, the third paragraph of the Discussion discusses the potential for cross-contamination within shared production facilities to influence our results. We note that our design was developed to test for significant effects of type of chicken from the perspective of the consumer making decisions about which chicken to purchase. Thus, while farm-to-farm variability and cross-contamination are important potential sources of variation in antibiotic resistance, incorporating this variance is an important part of our design. Future, more exhaustive surveys could attempt to partition the influence of these factors, but doing so was beyond the scope of the current study.

See referee reports

Introduction

The use of antibiotics in livestock production may pose health risks to humans, as such usage has been correlated with the occurrence of antibiotic-resistant bacteria isolated from human infections^{1,2}. Methods of livestock production differ in antibiotic use, and this can influence the frequency of antibiotic-resistant bacteria on retail meats. For example, antibiotic-resistant *Escherichia coli* has been shown to be less common on poultry raised without antibiotics (RWA) as compared to poultry raised conventionally³. Likewise, organic poultry can have lower frequencies of antibiotic-resistant bacteria than poultry raised conventionally⁴⁻¹⁰, although this is not always the case¹¹⁻¹³. Organic, RWA, and kosher food products supply a growing market niche¹⁴. Consumers perceive that they offer health benefits¹⁴⁻²¹ and are willing to pay a premium for them²²⁻²⁴. The actual health benefits of organic food are not always clear²⁵, and the health benefits of kosher foods are largely anecdotal. Little is known about the frequency of antibiotic-resistant microorganisms on kosher products.

The organic and RWA labels require specific production methods as stipulated in US federal regulations, whereas the kosher label adheres to religious requirements that are regulated privately. The RWA label requires that "livestock have never received antibiotics from birth to harvest"²⁶. The United States Department of

Agriculture (USDA) organic standard is only slightly less strict, stipulating that "The producer of an organic livestock operation must not sell, label, or represent as organic any animal or edible product derived from any animal treated with antibiotics", but also that "Poultry or edible poultry products must be from poultry that has been under continuous organic management beginning no later than the second day of life"^{26,27}. Therefore, injecting antibiotics into eggs or administering them during the first 24 hours of the chick's life will not violate the letter of the USDA organic standard^{28,29}. Kosher production differs from organic and RWA in that it is inherently predicated on religious requirements. For kosher meat, the major requirements are that it must be from animals that have split hooves and chew their cud, it must not be mixed with dairy products, and all equipment used must be used exclusively for kosher food¹⁹. Animals must be slaughtered "humanely", and meat is typically salted to remove blood rapidly, a practice that has been shown to reduce the microbial load³⁰. Unlike for organic and RWA, kosher poultry is not regulated by Federal laws but rather by private certification organizations, and thus the specific practices vary¹⁹.

Here, we compared four major types of poultry—conventional, kosher, organic, and RWA—in order to assess the frequency of contamination with antibiotic-resistant *E. coli*. We focused on poultry products from a major metropolitan center (the greater New York City area) and products available to typical consumers by studying multiple brands of chicken from multiple stores. Our goal was to compare the frequency of antibiotic-resistant *E. coli* in these four categories of chicken.

Methods

Sample collection

During April–June 2012, raw chicken was purchased from supermarkets, butcher shops, specialty stores, and food distributors in the greater New York City area. A variety of widely available brands were procured in four categories: conventional, kosher, organic and RWA. Within each category of chicken purchased, we collected at least four samples of each brand. Some samples included more than one category (e.g., kosher and organic). Five collections occurred resulting in 213 total samples. Samples were drumsticks or samples from which drumsticks were removed for analysis (all with skin). After purchase, each chicken sample was placed in a labeled, ziplock bag, and placed in a cooler with ice packs. Three coolers with ice packs were shipped overnight to T-Gen North within two days of collection.

Laboratory analyses

Chicken samples arrived at the laboratory in their original packaging and were refrigerated at 4°C until processed. One putative *E. coli* strain was isolated and screened from each sample using standard methods for assaying for antimicrobial resistance described by the Clinical and Laboratory Standards Institute (CLSI)³¹. The use of one strain per sample enabled efficient testing among a population of chicken samples for differences in the frequency of antibiotic resistance.

One whole drumstick was selected from each package or removed from each whole chicken sample using a sterilized knife. Each sample was transferred aseptically to a Stomacher Bag (VWR, Radon,

PA, USA, catalog number 11216–902) containing 250 ml MacConkey broth (Alpha Biosciences, Baltimore, MD) and agitated at speed 7 for 3 min on a rocking platform shaker (VWR, Radon, PA, USA, model no. 40000–302) and incubated overnight at 44°C. A 10 µl loop was used to inoculate a VRBA+MUG (Teknova, Hollister, CA) plate with the enriched broth. The plate was incubated at 37°C for 2 h and then at 44°C for 22 h, along with QA/QC strains ATCC *E. coli* 35218, *Klebsiella pneumoniae*, *Hafnia alvei*, *Citrobacter freundii*, and *Serratia plymuthica*. QA/QC strains not listed as ATCC were isolated and identified using the BD Phoenix at Flagstaff Medical Center. From each VRBA+MUG plate, four putative *E. coli* colonies were streaked to CHROMagar (Hardy Diagnostics, Santa Maria, CA) and incubated 20 to 24 h at 37°C. One putative *E. coli* colony, appearing pink to rose, was streaked to a second CHROMagar plate and incubated 20 to 24 h at 37°C. For each sample, a putative *E. coli* isolate was inoculated into an assigned well of a 96-well plate containing 75 µl of Tris EDTA (TE) buffer. DNA was released from cell suspension with a thermal cycler (Bio-Rad, Hercules, CA) using the following parameters: heated lid, 95°C; block temperature, 90°C for 15 min. To confirm the identity of putative *E. coli* isolates, a *uidA* qPCR assay and a universal bacterial qPCR (BactQuant³²) were used. For each reaction, 2 µl of DNA was added into 8 µl of master mix, with the final reaction containing 1.8 µM of each forward and reverse *uidA* primer, 0.25 µM *uidA*-VIC probe, 0.90 µM of each forward and reverse Pan16S primer, 0.25 µM Pan16S-FAM probe, 1X QuantaPerfeCTa® Multiplex qPCR SuperMix wROX (Quanta Biosciences, Gaithersburg, MD) and molecular-grade water. All samples were run in triplicate and each experiment included a standard curve and no-template controls. The 7900HT Real-Time PCR System (Applied Biosystems, Carlsbad, CA) was used to run the reactions with following conditions: 3 min at 50°C for UNG treatment, 10 min at 95°C for *Taq* activation, 15 s at 95°C for denaturation and 1 min at 60°C for annealing and extension x 40 cycles. Six isolates were excluded from further analysis because they were not confirmed as *E. coli* using the qPCR assay.

Guidelines from the Clinical and Laboratory Standards Institute (CLSI) for disk diffusion methods³¹ were used to test each strain for resistance to antibiotics. Some strains did not grow under assay conditions (n=23) and were excluded from further analysis. Twelve antibiotics were tested, representing seven classes of drugs: tetracycline (class, tetracyclines); ampicillin and ampicillin sulbactam (class, penicillins); cefazolin, cefoxitin, and ceftriaxone (class, cephalosporins); gentamicin and amikacin (class, aminoglycosides); nalidixic acid and ciprofloxacin (class, quinolones); trimethoprim sulfamethoxazole (class, folate pathway inhibitors); and imipenem (class, carbapenems) (VWR, Radon, PA). Breakpoint guidelines from the CLSI M100 Tables 2A through 2J for *E. coli*³¹ were used to classify strains into “resistant”, “intermediate” or “susceptible”; designations of “intermediate” were lumped with “resistant” for purposes of statistics and inference, a conservative approach with respect to consumer safety.

Statistical analyses

Analysis of variance (ANOVA) was used to test whether antibiotic resistance varied among the brands of chicken sampled, using SYSTAT 13.1. Effects of brand within each category were tested

(i.e., using all the data within conventional, organic, kosher, RWA). For each drug, Microsoft Excel for Mac Version 14.1.0 was used to conduct chi-square tests to determine whether the frequency of resistance varied among categories of chicken: conventional, organic, kosher and RWA.

The total number of drugs and drug classes to which each strain was resistant were enumerated. One-way ANOVA was used to compare the average number of drugs to which strains were resistant among categories, using samples with only one category designation (n=120). This test captures the effect of a consumer’s choice whether to purchase chicken in one category over another on the likelihood of exposure to antibiotic-resistant *E. coli*.

Multi-factor ANOVA was used to test whether trends held across the broader dataset (n=184), including samples with multiple category designations. The collection of samples included adequate replication (>14) for every possible two-way combination of labels (organic & kosher, RWA & organic, and RWA & kosher). Replication for the three-way combination (organic, kosher & RWA) was low (n=5), and all samples were from one brand. To avoid bias, these samples were excluded from the ANOVA. Each of the three labeling categories was included as a factor in three-way ANOVAs (organic, RWA, and kosher, each with two levels), with the number of drugs and drug classes exhibiting resistance as response variables. This tests for the effect of each category and for interactive effects of combining categories.

Results

Across the entire dataset, resistance to cefazolin was most common (41.3%), followed by ampicillin (31.5%), tetracycline (30.4%), and ampicillin sulbactam (19.6%). Some resistance was detected for cefoxitin, (12.5%) and gentamicin (10.9% of strains), but no strain was resistant to amikacin, the other aminoglycoside tested. For the quinolones, some (3.3%) of strains were resistant to nalidixic acid, but none was resistant to ciprofloxacin. Resistance was low (3.3%) for trimethoprim sulfamethoxazole, the one folate pathway inhibitor tested, and was absent for imipenem, the one carbapenem tested. Over half of all strains collected exhibited resistance to one or more antibiotics: 55%, 58%, 60%, and 76% from conventional, RWA, organic, and kosher chicken samples, respectively.

Within categories of chicken purchased, brands did not vary in the extent of antibiotic resistance (Table 1). By contrast, categories of chicken differed in the number of drugs to which strains of *E. coli* were resistant (Figure 1). Strains of *E. coli* isolated from kosher chicken were resistant to more drugs than were strains from the other categories (Tukey’s HSD comparisons: kosher vs. conventional, P=0.023; kosher vs. organic, P=0.041; kosher vs. RWA, P=0.002).

These patterns held when analyzing the broader dataset, including the samples with multiple designations. Strains of *E. coli* isolated from kosher chicken samples were resistant to more drugs compared to the other categories (Figure 2). Strains of *E. coli* isolated from samples in the RWA category tended to be resistant to fewer drugs but the difference was not significant versus conventional and organic which did not differ from each other.

Table 1. Results from four one-way ANOVA testing for the effect of brand on *E. coli* drug resistance. The response variable was the number of drugs to which strains of *E. coli* exhibited resistance. N indicates numbers of brands within each category. The P-values are for the effect of brand, tested for each category.

Category	N	P-value
Conventional	9	0.129
Organic	13	0.367
Kosher	10	0.789
RWA	14	0.607

Laboratory assay assessing antibiotic resistance in isolates of *Escherichia coli* from retail chicken collected in the New York metropolitan area

2 Data Files

<http://dx.doi.org/10.6084/m9.figshare.731681>

Discussion

Poultry growers use antibiotics both for therapeutic purposes and for growth promotion^{33,34}. Based on a national survey conducted by the USDA of poultry and hog producers in the United States, use of antibiotics at sub-therapeutic levels for growth promotion

is common^{35,36}. One estimate places growth promotion in livestock production as the single largest sector in which antibiotics are used in the US, accounting for 70% of the total of 50 million pounds for the year 2008³⁷. The use of antibiotics in poultry production can select for antibiotic-resistant microorganisms including *Salmonella*, *Campylobacter*, *Enterococcus*, and extra-intestinal pathogenic *E. coli*³⁸. Studies of *E. coli* from bloodstream infections in Europe suggest that poultry are an important source of antibiotic-resistant infections³⁹. Use of antibiotics is restricted in production of chicken carrying the USDA organic and USDA RWA labels. Like conventional chicken, chicken with a certified kosher label does not indicate any special restrictions in the use of antibiotics.

Our finding that brands within categories did not differ significantly in the extent of antibiotic resistant *E. coli* (Table 1) could arise from the fact that individual brands of chicken obtain product from multiple farms whose production practices may differ, obscuring clear patterns associated with individual brands. Our ability to detect an effect of brand might also be constrained by low statistical power. Our finding that the frequency of antibiotic resistant strains of *E. coli* on organic poultry did not differ significantly from conventional (Figure 1 and Figure 2) reflects some past studies in this area that have found no difference in antibiotic resistance between organic and conventional practices¹¹⁻¹³. Others found that pathogens on organic or RWA poultry products had lower resistance to antibiotics compared to conventional products^{4,10,40-43}, which was the trend we

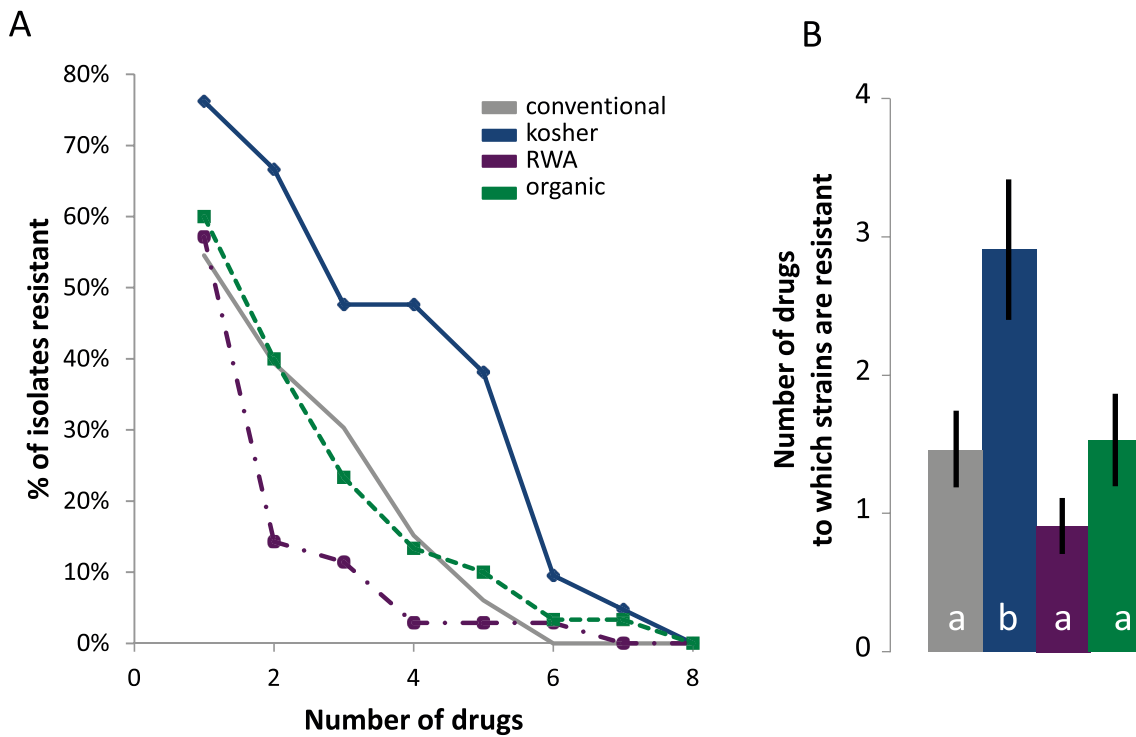


Figure 1. A. The percentage of resistant strains of *E. coli* as a function of the number of drugs tested for each of the four categories of chicken sampled. Values shown on the x-axis are cumulative. For example, the percentage of strains resistant to five or more drugs includes strains resistant to five to seven drugs. **B.** The average number of drugs to which strains of *E. coli* exhibited resistance in each of the four categories of chicken sampled. Values shown are means ± standard errors of the mean. Category was a significant factor in a one-way ANOVA (P=0.003). Bars with different letters are significantly different at P<0.05 (Tukey’s HSD). RWA-raised without antibiotics.

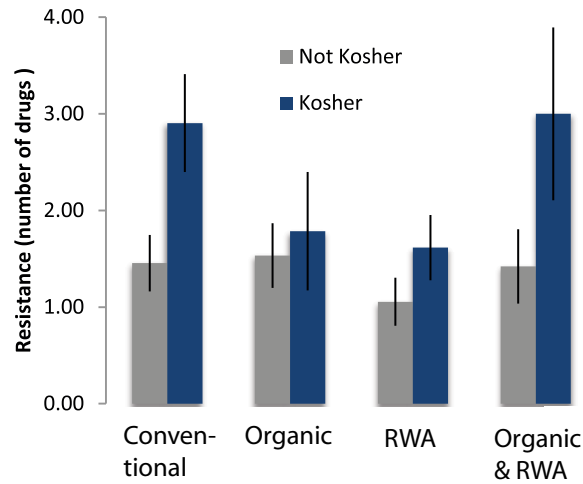


Figure 2. Antibiotic resistance across all categories tested, showing the number of drugs to which strains of *E. coli* were resistant among categories. Values shown are means \pm standard errors of the mean. Kosher was a significant factor in the analysis of variance ($P=0.00374$), whereas 'raised without antibiotics' (RWA) ($P=0.122$), organic ($P=0.874$), and all interactions ($P<0.050$) were not significant.

observed for RWA. The distinction between USDA organic from USDA RWA may be important, given that organic chicks can receive antibiotics via *in ovo* injections and during the first day of life. Previous studies have provided unequivocal evidence that even *in ovo* injection of antibiotics can affect the susceptibility of the bacteria that contaminate poultry products². With a larger sample, the tendency for *E. coli* isolated from RWA samples to have lower frequency of antibiotic resistance than other categories ($P=0.122$; Figure 1 and Figure 2) may emerge as significant.

Cross-contamination is another possible source of antibiotic resistance⁴⁴. Shared facilities for product and slaughter could promote cross-contamination and antibiotic strains could be spread among

organism and environments^{45,46}. Poultry could then be inadvertently exposed to antibiotic-resistant *E. coli*. For example, companies with both conventional and organic products may slaughter in the same facilities, promoting cross-contamination. Production facilities that convert from one practice to another could also experience residual contamination, though there is evidence that converting from conventional to organic can reduce frequency of resistance⁸. The identification of possible cross-contamination is outside the scope of this study, but these possibilities would need to be considered when investigating the sources of antibiotic resistance.

The increased resistance of *E. coli* in kosher chicken compared to conventional was surprising, because, while kosher does not stipulate anything about antibiotic use, kosher is perceived as clean and safe to consume¹⁹. The higher resistance found in isolates from kosher chicken (Figure 1 and Figure 2), and the distinct antibiotic-resistance profile (Table 2) suggests that use of antibiotics in the kosher production chain is common and that it may be more intensive than use of antibiotics among conventional, organic, or RWA practices. It is not immediately obvious where in the kosher chicken production process antibiotic use might be more prevalent, or where exposure to antibiotic-resistant organisms is more likely. Consumers perceive organic, kosher and RWA products to be healthier¹⁴⁻²¹, though the real health benefits from organic products are unclear¹⁰, and, to our knowledge, the actual health benefits of kosher have not been assessed. Our findings are consistent with the suggestion that some 'niche market' products, while perceived to be safer, may have higher incidence of foodborne pathogens compared to conventional products⁴⁷.

Our study was limited in geographic and temporal scale, as we focused on the New York metropolitan area over a three-month time period. Yet, the region is large and populous, we focused on the most widely available brands in all categories, and this area particularly offered multiple kosher brands. Our final sample size was limited ($n=184$) but not atypical for the field⁴⁸⁻⁵¹. Finally, we only assayed for generic *E. coli* and did not assess virulence or virulence group assignments for each sample. However, *E. coli* is a useful focal organism because it is widespread and an important potential pathogen.

Table 2. Antibiotic-resistance profiles of conventional, organic, kosher and 'raised without antibiotics' (RWA) chicken products. Bold text denotes significant differences among categories according to one-way ANOVA.

Antibiotic	Conventional	Organic	Kosher	RWA	P-value
Ampicillin	24%	33%	62%	14%	0.002
Ampicillin sulbactam	18%	13%	52%	8%	0.001
Cefazolin	30%	43%	62%	31%	0.072
Cefoxitin	3%	10%	33%	6%	0.003
Ceftriaxone	3%	7%	33%	6%	0.001
Nalidixic acid	3%	3%	5%	3%	0.981
Gentamicin	24%	13%	5%	11%	0.206
Tetracycline	30%	30%	33%	25%	0.917
Trimethoprim sulfamethoxazole	9%	0%	5%	3%	0.321

More studies are needed to test whether antibiotic resistance among kosher products is consistently higher than conventional and other categories. Nevertheless, our study offers insight into another area of the food production system increasing the exposure of people to microorganisms that are resistant to antibiotics. In addition to regulation, more consistent surveillance or auditing would add of consumer protection, enabling improved purchase decisions based on price and health benefits guided by meaningful labels.

Author contributions

JMM, ARM, JCM, LBP, and BAH designed the study. JMM and ARM collected the samples. KW and HG carried out the laboratory

analyses. JMM and BAH analyzed the data. All authors contributed to writing the manuscript.

Competing interests

No competing interests were disclosed.

Grant information

This work was funded by the Merriam-Powell Center for Environmental Research and the Ecosystem Science & Society Center at Northern Arizona University.

The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

References

- Silbergeld EK, Graham J, Price LB: **Industrial food animal production, antimicrobial resistance, and human health.** *Annu Rev Public Health.* 2008; **29**: 151–169.
[PubMed Abstract](#) | [Publisher Full Text](#)
- Dutil L, Irwin R, Finley R, *et al.*: **Ceftiofur Resistance in Salmonella enterica Serovar Heidelberg from Chicken Meat and Humans, Canada.** *Emerg Infect Dis.* 2010; **16**(1): 48–54.
[PubMed Abstract](#) | [Publisher Full Text](#) | [Free Full Text](#)
- Zhang J, Massow A, Stanley M, *et al.*: **Contamination Rates and Antimicrobial Resistance in Enterococcus spp., Escherichia coli, and Salmonella Isolated from “No Antibiotics Added”-Labeled Chicken Products.** *Foodborne Pathog Dis.* 2011; **8**(11): 1147–1152.
[PubMed Abstract](#) | [Publisher Full Text](#)
- Miranda JM, Guarddon M, Mondragon A, *et al.*: **Antimicrobial resistance in Enterococcus spp. strains isolated from organic chicken, conventional chicken, and turkey meat: A comparative survey.** *J Food Prot.* 2007; **70**(4): 1021–1024.
[PubMed Abstract](#)
- Miranda JM, Mondragon A, Vazquez BI, *et al.*: **Microbiological quality and antimicrobial resistance of Escherichia coli and Staphylococcus aureus isolated from conventional and organic “Arzu-Ulloa” cheese.** *Cyta-Journal of Food.* 2009; **7**: 103–110.
[Publisher Full Text](#)
- Miranda JM, Vazquez BI, Fente CA, *et al.*: **Antimicrobial resistance in Escherichia coli strains isolated from organic and conventional pork meat: A comparative survey.** *Eur Food Res Technol.* 2008; **226**(3): 371–375.
[Publisher Full Text](#)
- Young I, Rajic A, Wilhelm BJ, *et al.*: **Comparison of the prevalence of bacterial enteropathogens, potentially zoonotic bacteria and bacterial resistance to antimicrobials in organic and conventional poultry, swine and beef production: a systematic review and meta-analysis.** *Epidemiol Infect.* 2009; **137**(9): 1217–1232.
[PubMed Abstract](#) | [Publisher Full Text](#)
- Sapkota AR, Hulet RM, Zhang G, *et al.*: **Lower Prevalence of Antibiotic-Resistant Enterococci on U.S. Conventional Poultry Farms that Transitioned to Organic Practices.** *Environ Health Perspect.* 2011; **119**(11): 1622–1628.
[PubMed Abstract](#) | [Publisher Full Text](#) | [Free Full Text](#)
- Alvarez-Fernandez E, Cancelo A, Diaz-Vega C, *et al.*: **Antimicrobial resistance in E. coli isolates from conventionally and organically reared poultry: A comparison of agar disc diffusion and Sensi Test Gram-negative methods.** *Food Control.* 2013; **30**(1): 227–234.
[Publisher Full Text](#)
- Smith-Spangler C, Brandeau ML, Hunter GE, *et al.*: **Are Organic Foods Safer or Healthier Than Conventional Alternatives?: a systematic review.** *Ann Intern Med.* 2012; **157**(5): 348–66.
[PubMed Abstract](#) | [Publisher Full Text](#)
- LeJeune JT, Christie NP: **Microbiological quality of ground beef from conventionally-reared cattle and “Raised without antibiotics” label claims.** *J Food Prot.* 2004; **67**(7): 1433–1437.
[PubMed Abstract](#)
- Roesch M, Perreten V, Doherr MG, *et al.*: **Comparison of antibiotic resistance of udder pathogens in dairy cows kept on organic and on conventional farms.** *J Dairy Sci.* 2006; **89**(3): 989–997.
[PubMed Abstract](#) | [Publisher Full Text](#)
- Luangtongkum T, Morishita TY, Ison AJ, *et al.*: **Effect of conventional and organic production practices on the prevalence and antimicrobial resistance of Campylobacter spp. in poultry.** *Appl Environ Microbiol.* 2006; **72**(5): 3600–3607.
[PubMed Abstract](#) | [Publisher Full Text](#) | [Free Full Text](#)
- Cohen E, Schwartz Z, Antonovski R, *et al.*: **Consumer perceptions of kosher products.** *Journal of Foodservice Business Research.* 2002; **5**(3): 69–88.
[Publisher Full Text](#)
- Jolly DA, Schutz HG, Diazknauf KV, *et al.*: **Organic foods - consumer attitudes and use.** *Food Technology.* 1989; **43**: 60.
[Reference Source](#)
- Jolly DA: **Differences between buyers and nonbuyers of organic produce and willingness to pay organic price premiums.** *Journal of Agribusiness.* 1991; **9**: 97–111.
[Reference Source](#)
- Williams PR, Hammit JK: **A comparison of organic and conventional fresh produce buyers in the Boston area.** *Risk Anal.* 2000; **20**(5): 735–746.
[PubMed Abstract](#) | [Publisher Full Text](#)
- Williams PR, Hammit JK: **Perceived risks of conventional and organic produce: Pesticides, pathogens, and natural toxins.** *Risk Anal.* 2001; **21**(2): 319–330.
[PubMed Abstract](#)
- Campbell H, Murcott A, MacKenzie A: **Kosher in New York City, halal in Aquitaine: challenging the relationship between neoliberalism and food auditing.** *Agric Human Values.* 2011; **28**(1): 67–79.
[Publisher Full Text](#)
- Pino G, Peluso AM, Guido G: **Determinants of Regular and Occasional Consumers’ Intentions to Buy Organic Food.** *Journal of Consumer Affairs.* 2012; **46**(1): 157–169.
[Publisher Full Text](#)
- Shafie FA, Rennie D: **Consumer Perceptions towards Organic Food.** In: Abbass MY, Bajunid AFI, editors. *Proceedings of the 1st National Conference on Environment-Behaviour Studies.* Amsterdam: Elsevier Science Bv. 2012; **49**: 360–367.
[Publisher Full Text](#)
- Batte MT, Hooker NH, Haab TC, *et al.*: **Putting their money where their mouths are: Consumer willingness to pay for multi-ingredient, processed organic food products.** *Food Policy.* 2007; **32**(2): 145–159.
[Publisher Full Text](#)
- Krystallis A, Chrysosoidis G: **Consumers’ willingness to pay for organic food - Factors that affect it and variation per organic product type.** *Br Food J.* 2005; **107**(5): 320–343.
[Publisher Full Text](#)
- Yiridoe EK, Bonti-Ankomah S, Martin RC: **Comparison of consumer perceptions and preference toward organic versus conventionally produced foods: A review and update of the literature.** *Renewable Agriculture and Food Systems.* 2005; **20**(4): 193–205.
[Publisher Full Text](#)
- Brandt K, Leifer C, Sanderson R, *et al.*: **Agroecosystem Management and Nutritional Quality of Plant Foods: The Case of Organic Fruits and Vegetables.** *CRC Crit Rev Plant Sci.* 2011; **30**: 177–197.
[Publisher Full Text](#)
- USDA United States Standards for Livestock and Meat Marketing Claims.** In: Agriculture USDO, editor. FR 79552: Federal Register. 2002.
[Reference Source](#)
- Code of Federal Regulations t, part 205, subpart C. National Organic Program, Organic Production and Handling Requirements.** In: Regulations CoF, editor. 7. Code of Federal Regulations. 2012.
[Reference Source](#)

28. Crandall PG, Seideman S, Ricke SC, *et al.*: **Organic poultry: Consumer perceptions, opportunities, and regulatory issues.** *J Appl Poult Res.* 2009; **18**(4): 795–802.
[Publisher Full Text](#)
29. Fanatico AC, Owens CM, Emmert JL: **Organic poultry production in the United States: Broilers.** *J Appl Poult Res.* 2009; **18**(2): 355–366.
[Publisher Full Text](#)
30. Shin D, Kakani G, Molina VA, *et al.*: **Effect of kosher salt application on microbial profiles of poultry carcasses.** *Poult Sci.* 2012; **91**(12): 3247–3252.
[PubMed Abstract](#) | [Publisher Full Text](#)
31. **Clinical and Laboratory Standards Institute.** Performance Standards for Antimicrobial Susceptibility Testing M100–S21. 940 West Valley Road, Suite 1400, Wayne, Pennsylvania 19087–1898, USA: Clinical and Laboratory. 2011; *Standards Institute. pp. 178. Accessed 21 June 2013 from.*
[Reference Source](#)
32. Liu CM, Aziz M, Kachur S, *et al.*: **BactQuant: An enhanced broad-coverage bacterial quantitative real-time PCR assay.** *BMC Microbiol.* 2012; **12**: 56.
[PubMed Abstract](#) | [Publisher Full Text](#) | [Free Full Text](#)
33. MacDonald JM, Wang SL: **Foregoing sub-therapeutic antibiotics: the impact on broiler grow-out operations.** *Applied Economic Perspectives and Policy.* 2011; **33**(1): 79–98.
[Reference Source](#)
34. Ricke SC, Jarquin R, Hanning I: **Antimicrobials in animal feed: benefits and limitations.** Pages 411–431, in *Animal Feed Contamination*, Woodhead Publishing Series in Food Science, Technology and Nutrition No. 215. ISBN 978 1 84569 715 9.
[Publisher Full Text](#)
35. MacDonald JM, Wang SL: **Subtherapeutic Antibiotics and U.S. Broiler Production.** Economic Research Service, U.S. Department of Agriculture. Agricultural & Applied Economics Association's 2009 AAEA & ACCI Joint Annual Meeting, Milwaukee, WI, July 26–28, 2009.
[Reference Source](#)
36. McBride WD, Key N, Mathews K: **Sub-therapeutic Antibiotics and Productivity in U.S. Hog Production.** *Review of Agricultural Economics.* 2008; **30**(2): 270–288.
[Reference Source](#)
37. Dorit R: **Routes of resistance.** *Am Sci.* 2009; **97**: 20–22.
[Publisher Full Text](#)
38. Davis MF, Price LB, Liu CM, *et al.*: **An ecological perspective on US industrial poultry production: the role of anthropogenic ecosystems on the emergence of drug-resistant bacteria from agricultural environments.** *Curr Opin Microbiol.* 2011; **14**(3): 244–250.
[PubMed Abstract](#) | [Publisher Full Text](#)
39. Vieira AR, Collignon P, Aarestrup FM, *et al.*: **Association Between Antimicrobial Resistance in Escherichia coli Isolates from Food Animals and Blood Stream Isolates from Humans in Europe: An Ecological Study.** *Foodborne Pathog Dis.* 2011; **8**(12): 1295–1301.
[PubMed Abstract](#) | [Publisher Full Text](#)
40. Cui S, Ge B, Zheng J, *et al.*: **Prevalence and antimicrobial resistance of Campylobacter spp. and Salmonella serovars in organic chickens from Maryland retail stores.** *Appl Environ Microbiol.* 2005; **71**(12): 4108–4111.
[PubMed Abstract](#) | [Publisher Full Text](#) | [Free Full Text](#)
41. Miranda JM, Guarddon M, Vazquez BI, *et al.*: **Antimicrobial resistance in Enterobacteriaceae strains isolated from organic chicken, conventional chicken and conventional turkey meat: A comparative survey.** *Food Control.* 2008; **19**(4): 412–416.
[Publisher Full Text](#)
42. Han F, Lestari SI, Pu S, *et al.*: **Prevalence and Antimicrobial Resistance Among Campylobacter spp. in Louisiana Retail Chickens After the Enrofloxacin Ban.** *Foodborne Pathog Dis.* 2009; **6**(2): 163–171.
[PubMed Abstract](#) | [Publisher Full Text](#)
43. Lestari SI, Han F, Wang F, *et al.*: **Prevalence and Antimicrobial Resistance of Salmonella Serovars in Conventional and Organic Chickens from Louisiana Retail Stores.** *J Food Prot.* 2009; **72**(6): 1165–1172.
[PubMed Abstract](#)
44. Smith JL, Drum DJ, Dai Y, *et al.*: **Impact of antimicrobial usage on antimicrobial resistance in commensal Escherichia coli strains colonizing broiler chickens.** *Appl Environ Microbiol.* 2007; **73**(5): 1404–1414.
[PubMed Abstract](#) | [Publisher Full Text](#) | [Free Full Text](#)
45. Moodley A, Guardabassi L: **Clonal spread of methicillin-resistant coagulase-negative staphylococci among horses, personnel and environmental sites at equine facilities.** *Vet Microbiol.* 2009; **137**(3–4): 397–401.
[PubMed Abstract](#) | [Publisher Full Text](#)
46. Graham JP, Leibler JH, Price LB, *et al.*: **The animal-human interface and infectious disease in industrial food animal production: Rethinking biosecurity and biocontainment.** *Public Health Rep.* 2008; **123**(3): 282–299.
[PubMed Abstract](#) | [Free Full Text](#)
47. Fox JT, Reinstein S, Jacob ME, *et al.*: **Niche Marketing Production Practices for Beef Cattle in the United States and Prevalence of Foodborne Pathogens.** *Foodborne Pathog Dis.* 2008; **5**(5): 559–569.
[PubMed Abstract](#) | [Publisher Full Text](#)
48. Cui S, Ge B, Zheng J, *et al.*: **Prevalence and antimicrobial resistance of Campylobacter spp. and Salmonella serovars in organic chickens from Maryland retail stores.** *Appl Environ Microbiol.* 2005; **71**(7): 4108–4111.
[PubMed Abstract](#) | [Publisher Full Text](#) | [Free Full Text](#)
49. Lestari SI, Han F, Wang F, *et al.*: **Prevalence and antimicrobial resistance of Salmonella serovars in conventional and organic chickens from Louisiana retail stores.** *J Food Prot.* 2009; **72**(6): 1165–1172.
[PubMed Abstract](#)
50. Miranda JM, Guarddon M, Mondragon A, *et al.*: **Antimicrobial resistance in Enterococcus spp. strains isolated from organic chicken, conventional chicken, and turkey meat: a comparative survey.** *J Food Prot.* 2007; **70**(4): 1021–1024.
[PubMed Abstract](#)
51. Miranda JM, Guarddon M, Vázquez BI, *et al.*: **Antimicrobial resistance in Enterobacteriaceae strains isolated from organic chicken, conventional chicken and conventional turkey meat: a comparative survey.** *Food Control.* 2008; **19**: 412–416.
[Publisher Full Text](#)

Open Peer Review

Current Referee Status:



Version 2

Referee Report 17 September 2013

doi:10.5256/f1000research.2226.r1849



Irene Hanning

Food Science and Technology, University of Tennessee, Logan, TN, USA

All previous comments have been addressed by the authors.

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Competing Interests: No competing interests were disclosed.

Referee Report 09 September 2013

doi:10.5256/f1000research.2226.r1493



Katharina Stärk

Veterinary Epidemiology, Economics and Public Health, Royal Veterinary College, London, UK

The article reports the frequency of resistance phenotypes in chicken collected at retail level. The title of the article is appropriate.

The abstract is clearly written although the consequences of the findings are not clearly referred to. The findings are not really surprising as production methods are bound to impact on the level of resistance among bacteria such as *E. coli*. Also, I think the reference being made to consumers may be misleading as it may imply consumer risk. It would be helpful to provide more details on specific husbandry practices used for kosher chicken as readers may not be familiar with them.

Regarding the statistical method; I am not clear what the dependent variable for the ANOVA was. It should typically be a numerical not categorical variable, so I assume it was percentage? I understand that analysis was done by brand. So we have a multi-level clustering here (sample-brand-production system). Data should therefore be analysed in this way.

I assume that resistance was established as a binary variable. Note that it is recommended to move towards more quantitative measurement of resistance. The description of the statistical analysis is too superficial to conclude on validity of results. The number of samples was low.

It has been demonstrated that the extent and type of antimicrobial usage is hugely variable between farms

even within one production type (e.g. among conventional producers). It is therefore recommended to use data that allow for linking of resistance status in the product to the true exposure of the animal, i.e. to link retail back to pre-harvest. I know that this is difficult, but else evidence will remain weak.

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Competing Interests: No competing interests were disclosed.

Author Response 17 Sep 2013

Bruce Hungate, Northern Arizona University, USA

We agree with Dr. Stärk that production methods are likely to impact resistance among generic *E. coli*, as our study shows. Nevertheless, the finding is important, because products available to consumers differ in resistance profiles, according to production practices. The finding that kosher products have higher frequencies of antibiotic resistant *E. coli* is inconsistent with consumers' perception of kosher as safer and healthier than other options. For this reason, we think the findings are interesting and relevant to consumers.

Regarding the statistical methods, we appreciate Dr. Stärk's comments and the opportunity to clarify and provide more information.

First, the text describing Table 2 in versions 1 and 2 should read, '*Bold text denotes significant differences among categories according to Chi-square test*'. No ANOVAs were used for binary response variables (in this case, resistant or not resistant). For the test of brand effects, we used ANOVA on non-transformed count data, as reported in the text and in Table 1. We also used the Kruskal-Wallis rank-sum test, which is arguably better suited to count data as it does not require the assumption of a normal distribution (though we did not report those tests). With the Kruskal-Wallis tests, we also found no significant effect of brand within chicken categories. (We will include these results in the **next version**.) Therefore, we combined brands in our tests comparing drug resistance among categories, as shown in Figure 1B. As identified on the vertical axis in Figure 1B, the dependent variable in the ANOVA was the number of drugs to which strains were resistant (non-transformed). The result is identical using the Kruskal-Wallis rank sum test, which also identified a significant effect of category: chi-squared = 9.3891, df = 3, p-value = 0.02454.

We also used a general linear model assuming the Poisson distribution which is typical of count data, an approach that allows multiple mean comparisons using the 'multcomp' package in R. Tukey's post hoc tests from the GLM also supported the findings that *E. coli* from Kosher chicken samples were resistant to more drugs than conventional ($P=0.001$), organic ($P=0.002$), and RWA ($P<0.001$). Thus, our findings are robust and consistent across a number of statistical models.

We confirm that resistance was defined as a binary variable, as recommended by the Clinical and Laboratory Standards Institute, and as stated in the methods: '*Breakpoint guidelines from the CLSI M100 Tables 2A through 2J for E. coli (reference 31) were used to classify strains into "resistant", "intermediate" or "susceptible"; designations of "intermediate" were lumped with "resistant" for purposes of statistics and inference, a conservative approach with respect to consumer safety.*' Thus, our use of a binary variable for resistance is consistent with the most recent standards for evaluating resistance.

Nevertheless, we agree with Dr. Stärk that there is merit in considering resistance as a continuous function, and for this reason we provided the raw (continuous) data used to evaluate resistance (see the data deposited on Figshare). Thus, if new standards develop, or if interested readers wish, the raw continuous data are available for analysis.

We agree with Dr. Stärk that linking the resistance status of the food product to exposure of the animal to antibiotics would provide a stronger basis for causal inference about the source of resistance and identify ways that resistance could be mitigated. However, it would not affect the overall conclusion that production methods yield different frequencies of resistance in *E. coli*, a conclusion that our data clearly support. Obtaining data about on-farm use of antibiotics in the US is nearly impossible at the current time. We hope that analyses like ours help pave the way to greater openness in the industry with respect to the on-farm use of these powerful drugs, and therefore stronger inference about their impacts on food and people.

Competing Interests: no competing interests

Version 1

Referee Report 16 August 2013

doi:10.5256/f1000research.1766.r1506



Irene Hanning

Food Science and Technology, University of Tennessee, Logan, TN, USA

The study is of interest as this type of data is necessary to fully understand the use of antibiotics in animal production. The manuscript is well written and easy to understand. There are a few points that the authors need to address:

Methods:

- Please list the number of brands per category that were sampled as in Table 1. Also, please list the number of samples collected per brand. This information would be helpful and may have some impact on the data.

Results:

- The total number of *E. coli* isolates collected per type or brand is not stated. It would be helpful to know what percentage of each were positive.

Discussion:

- The first sentence of the discussion section is very inflammatory to the industry and is not absolutely true. I would suggest refining this greatly or deleting it.
- Similarly, the second sentence is quite definitive and implies that antibiotic usage always creates antibiotic resistance which may not be true. I suggest modifying this sentence with a qualifying word such as “may select for” or “can select for”.

One variable the authors did not address is the fact that chickens produced by the same brand most likely came from different farms. Because there seems to be a large number of brands sampled, this further adds to the total number of farms that were likely to be sampled. The farm environment does have some impact on the quality of the food. Further, birds from multiple farms may be processed within the same processing plant and this too can impact the microbiological quality of the carcass due to cross-contamination. These are confounding variables that may have impacted the author's data.

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Competing Interests: No competing interests were disclosed.

Author Response 02 Sep 2013

Bruce Hungate, Northern Arizona University, USA

We appreciate Dr. Hanning's comments and suggestions and have revised the manuscript to address each point raised.

The number of samples collected per brand is now indicated in the text. The number of brands per category is listed as 'N' in Table 1.

We now state, by type of chicken collected, the percentages of isolates positive for some degree of antibiotic resistance in the fifth sentence of the Results section.

We have revised a few sentences in the Discussion for clarity and to remove potentially inflammatory or unsupported claims. We have added several citations that provide support for our statements, and at the same time, we removed potentially inflammatory adjectives. We also add a statement about one specific estimate of the extent of antibiotic usage for growth promotion. We realize such estimates are controversial, but we feel that these provide important and useful context for readers in the field. For the second sentence in the original, we have followed Dr. Hanning's suggestion to modify the claim by changing '*select*' to '*can select*'.

We appreciate the point that farm-to-farm variability could play a role in our results, and have added a sentence acknowledging this explicitly. Also, the third paragraph of the Discussion discusses the potential for cross-contamination within shared production facilities to influence our results. We note that our design was developed to test for significant effects of type of chicken from the perspective of the consumer making decisions about which chicken to purchase. Thus, while farm-to-farm variability and cross-contamination are important potential sources of variation in antibiotic resistance, incorporating this variance is an important part of our design. Future, more exhaustive surveys could attempt to partition the influence of these factors, but doing so was beyond the scope of the current study.

Competing Interests: No competing interests were disclosed.

Referee Report 23 July 2013

doi:10.5256/f1000research.1766.r1186



Marilyn Roberts

University of Washington, Seattle, WA, USA

This paper is of interest because it compares chickens raised by conventional, organic, raised without antibiotics, and kosher chickens for the prevalence of antibiotic resistant *E. coli*.

The finding that organic and conventionally raised chickens were statically indistinguishable while chickens raised without antibiotics tended to be slightly lower once again raises the question of the tangible and potential health advantages to the consumer of eating organically raised/raised without antibiotic vs. conventionally raised poultry. Why kosher products had higher prevalence of antibiotic resistant *E. coli* and *E. coli* which were multi-resistant is a new finding and certainly needs further study.

Whether statistical differences in the raised without antibiotic animals would have been found if larger numbers were tested is not clear. However this study continues to fuel the debate on whether the use of antibiotics as growth promoters in poultry production leads to selection of antibiotic resistant and multi-resistant bacteria; which ultimately may have consequences for treatment of diseases in both man and animals. This issue has been settled in the EU which has banned the practice, but is of major discussion currently in the US Congress where "The Strategies to Address Antimicrobial Resistance (STAAR)" (which would take important steps to strengthen the US federal response to the public health crisis of antimicrobial resistance) is currently being considered.

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Competing Interests: No competing interests were disclosed.

Author Response 02 Sep 2013

Bruce Hungate, Northern Arizona University, USA

We very much appreciate Dr. Roberts' comments on our study.

Competing Interests: No competing interests were disclosed.