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Social-technical interventions to reduce antimicrobial resistance in agriculture: evidence from poultry Farmer Field Schools in Ghana and Kenya

Mark A. Caudell[1]*, Stella Kiambi[1], Kofi Afakye[2], Eric Koka[3], Emmanuel Kabali[4], Tabitha Kimani[1] and Alejandro Dorado-Garcia[4]

[1]Food and Agriculture Organization of the United Nations, Nairobi, Kenya; [2]Food and Agriculture Organization of the United Nations, Accra, Ghana; [3]Department of Sociology and Anthropology, University of Cape Coast, Cape Coast, Ghana; [4]Food and Agriculture Organization of the United Nations, Rome, Italy

*Corresponding author. E-mail: mark.caudell@fao.org

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Objectives: To assess the feasibility of the Farmer Field School approach to address the complex problem of antimicrobial resistance in agriculture, specifically within small-to-medium-scale layer poultry systems in Ghana and Kenya. Impact was assessed across three domains relevant to the emergence and selection of antimicrobial resistance, including infection, prevention, and control practices, engagement with animal health professionals, and knowledge, attitudes, and practices on antimicrobial use and antimicrobial resistance.

Methods: Farmer Field Schools were held in Ghana ($N = 2$) and Kenya ($N = 3$) across an eight-month period with an average of 18 participants in each school. After completion, a quantitative evaluation survey was administered to participants and a sample of non-participants (Ghana; $N = 97$) (Kenya; $N = 103$). Logistic and ordinary least squares regression were used to assess differences between participants and non-participants on the three domains.

Results: Participation in a layer poultry Farmer Field School in Ghana and Kenya is associated with self-reported reductions in antibiotic use, particularly for prevention, an increased investment in farm infection, prevention, and control practices, including the use of footbaths and personal protective equipment, and enhanced engagement with animal health professionals.

Conclusions: Antimicrobial resistance is a complex problem driven by a wide range of practices and multiple stakeholders. To holistically address these factors requires the use of complex intervention approaches. The Farmer Field School approach offers a complex intervention methodology that can reduce the emergence and spread of antimicrobial resistance in agricultural systems through targeting the variety of on-farm and off-farm factors that drive resistance.

Introduction

Antimicrobial resistance (AMR) – when microorganisms such as bacteria and viruses acquire tolerance to antimicrobial drugs rendering these drugs less effective – is a complex problem. Numerous and interacting factors impact the selection and transmission of acquired AMR within and between people, their animals, and the environment. These factors include antimicrobial use (AMU), in particular: the overuse and misuse of drugs; the extent to which infection prevention and control (IPC) and biosecurity practices are observed in hospitals, on farms, and in homes; the sanitation infrastructures of villages and cities; and national health and economic policies and regulations.[1–4] These factors involve the behaviours of a wide range of stakeholders (e.g. consumers, farmers, doctors/veterinarians, policy makers, etc.) who are themselves motivated by socio-cultural, historical, political, economic, and personal forces.[1,5] Considering the diversity of factors and actors impacting AMR, addressing the problem demands the development of holistic interventions. An approach that has emerged out of public health, dubbed 'complex interventions', is well suited to AMR as complex interventions usually target multiple outcomes (e.g. AMU and IPC) and include several interacting components (e.g. farmers, veterinarians, consumers) that often necessitate the development of new behaviours by those who receive and deliver the intervention.[6]

The necessity of addressing AMR through a complex intervention approach is reflected in the broad range of interventions that have been targeted at the users, sellers, and prescribers of antimicrobial drugs.[7–12] A recent review of interventions to limit AMU and AMR in the agricultural sector classifies these interventions into AMR-sensitive and AMR-specific interventions. AMR-sensitive interventions indirectly address AMR. For example, an intervention that limits the introduction and spread of pathogens by improving farm IPC can reduce the need for antimicrobials, thereby indirectly impacting AMR. In agriculture, common AMR-sensitive interventions include application of biological and chemical products to eliminate pathogens, modification of farm infrastructures and materials, and educational/behavioural interventions to limit disease.[13] Efforts to promote vaccine uptake by farmers would also be considered an AMR-sensitive intervention and the role of vaccinations in reducing AMR is routinely highlighted.[14–16] The main objective of AMR-specific interventions is to reduce AMR, for example, by requiring farmers to acquire prescriptions prior to purchasing antibiotics.[17] Most AMR-specific interventions focus on improving antimicrobial stewardship, such as the 'Yellow-Card Scheme' in Denmark, which gives farms with high AMU a yellow card followed by increased supervision and a 'red card' if measures to decrease AMU are not successful.[18] While evaluations of both AMR-sensitive and AMR-specific interventions find mixed support[13,19,20] there is a general consensus that AMR reduction will require the implementation of both AMR-specific and AMR-sensitive interventions.[5,13,21]

A complex intervention methodology that can incorporate both AMR-sensitive and AMR-specific interventions is the Farmer Field School (FFS) approach. Pioneered by the Food and Agriculture Organization (FAO) in the late 1980s, FFSs are based on the principles of adult-centred learning (e.g. 'learning-by-doing') and the exchange and creation of knowledge through group-level problem solving.[22] In a typical FFS, a group of farmers (15–20) meet on a weekly basis at a demonstration farm over the course of a production cycle (e.g. 6 weeks for broiler poultry). The school proceeds under the guidance of a trained FFS facilitator(s), who is often a local animal health, agricultural extension worker, or a graduate from a prior FFS. Specifics of FFS implementation are based upon analysis of the production ecosystem by FFS participants, the identification of problems arising from this analysis, and the development and implementation of solutions. A central aspect of the FFS methodology is experimentation, with alternative production practices being tested, for example, rearing some layers on manufactured feeds while other layers are administered home-made feeds. FFS participants then observe how these varying practices impact growth, health, and production. Assessments of FFS have found the intervention can produce gains in knowledge and empowerment, although evidence on economic impacts and farmer-to-farmer transmission of FFS contents is limited, and those in the development community have questioned the sustainability of the approach.[22,23]

In this study, we assessed the feasibly of the FFS approach to address the complex problem of AMR in agriculture, specifically within layer poultry systems. Building upon results from extensive knowledge, attitudes, and practices studies,[5] we developed an FFS curriculum that addressed three domains, including the AMR-sensitive interventions of farm biosecurity and animal health seeking practices, and the AMR-specific intervention of promoting more prudent AMU. The schools were held with small-to-medium-scale layer farmers from Ghana and Kenya. We evaluated the effectiveness of the FFS in respect to addressing the three domains of AMU, IPC, and animal health seeking. Results from this analysis, along with qualitative data from participants and facilitators on challenges and successes, are then used to extend recommendations on how to use the FFS intervention approach to address AMR in agriculture.

Methods

Study locations

FFS were held within communities where knowledge, attitudes, and practices (KAP) surveys were conducted in 2019 to identify the behavioural drivers of AMU and AMR.[5] In Kenya, the three FFS were held in Gatundu North Sub-County, which is the highest commercial layer producing sub-county in the country. Likewise, the two FFS held in Ghana took place in Dormaa Municipality, which is the highest commercial poultry municipality in the country.[24] See Figure 1 for approximate locations of the FFS and Caudell *et al*.[5] for more information on study locations.

Development of layer Farmer Field Schools and participant selection

FFS development in Kenya and Ghana followed the same process. First, the FAO research team identified within-country Master FFS Trainers with experience in training facilitators for livestock FFS. Second, FFS facilitators were recruited in Kenya ($N = 6$) and Ghana ($N = 4$) to receive multi-week training by the Master FFS Trainers. Facilitators in Kenya were research assistants who had contributed to the earlier KAP study and lived within the targeted communities. In Ghana, facilitators were animal health professionals who worked within the targeted communities and who had also been involved in the original KAP study.[5] During the training, an outline of the layer FFS curriculums was collaboratively developed by the Master Trainers, facilitators, and FAO research personnel. Curriculums included FFS sessions covering best practices in layer farming and included sessions to address gaps identified by previous KAP studies, including gaps in knowledge, attitudes, and practices related to antimicrobial use and antimicrobial resistance, animal health seeking practices, and biosecurity.

FFS participants were recruited by first approaching farmers who had provided data during the KAP surveys. In both countries, selection was then expanded through word of mouth until 15–20 farmers agreed to participate for each school, with Ghana holding two FFSs and Kenya three FFSs. FFSs in Ghana and Kenya meet on a weekly basis for approximately 32 weeks. This schedule was chosen according to the average length of time between the arrival of day-old chicks on the farm to the peak of egg laying. The FAO was responsible for all costs involved with the field school except for participant transport costs to the school. In Kenya, however, an issue with the distribution of funds resulted in FFS participants having to temporarily use their own funds to buy feed. Weekly meetings were occasionally interrupted by government-instituted COVID-19 restrictions and some lessons combined two sessions to make up for the lost time. All FFS were required to observe government instituted social distancing guidelines, wore masks, and washed hands and boots prior to entering and exiting the demonstration farms. See Table 1 for specific locations of FFS and number of participants.

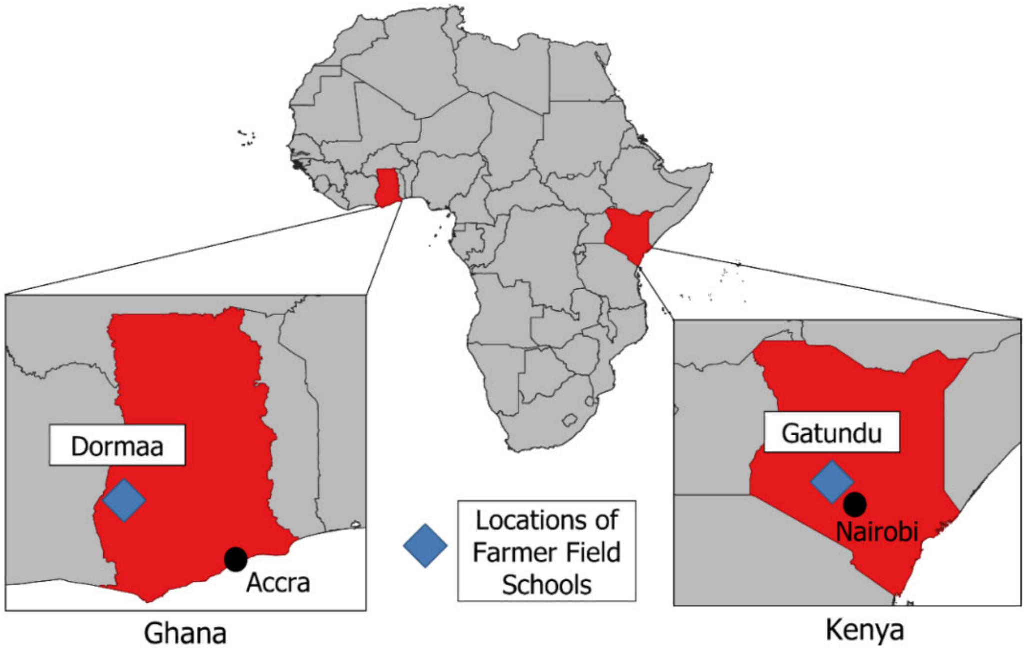

Figure 1. Approximate locations of Farmer Field Schools in Ghana and Kenya. See map legend for description of map markers. Maps were created using QGIS. Base layers for the map were downloaded from © OpenStreetMap contributors http://www.vdsgeo.com/osm-data.aspx and licensed under Creative Commons Attribution-ShareAlike 2.0. The map was created using QGIS, version 3.14.

Table 1. Locations of field schools and numbers of participants

Country/location	No. of FFS participants
Ghana	
Dormaa	20
Wamfie	23
Kenya	
Kahuroko	18
Kimerera Nguna	16
Mangu	18

Evaluation survey development and deployment

To assess the effectiveness of FFS in addressing AMR in layer production systems, a cross-sectional survey was conducted among all FFS participants ($N = 95$, Ghana = 43, Kenya = 52) and a sample of layer farmers who were not involved in the FFS ($N = 105$, Ghana = 54, Kenya = 51). The sample of non-FFS respondents was purposively selected through a respondent-driven sampling approach, with project personnel and FFS participants providing the names of individuals currently engaged in layer production that were not in the FFS. Importantly, the sampled layer farmers in Ghana and Kenya should not be considered representative of all layer farmers in our targeted geographical domains. As such, statements such as 'Kenyan layer farmers' should be considered to mean 'Kenyan layer farmers surveyed in this study'.

The FFS evaluation survey combined questions from a previously implemented KAP survey[5] with questions specific to the FFS, including participant attendance and the perceived benefits and challenges of the FFS (see the Kenyan questionnaire available as part of the Supplementary data at *JAC-AMR* Online). Enumerators received 3–4 days training and assisted in refining the surveys, which were piloted to ensure question clarity and estimate survey times. For non-FFS participants, enumerators were instructed to survey the household head, farm manager, or spouse of household head if involved in layer farming. The survey took between 45 and 90 minutes to complete. The survey was administered using the Kobo Collect® application on tablets.

Data transformation, modelling, and diagnostics

The impacts of FFS participation were evaluated across three general domains related to AMR including: (i) knowledge, attitudes, and practices directly related to AMU and AMR; (ii) general animal health seeking practices; and (iii) a range of IPC practices. Table 2 provides the survey questions that represent each domain. For example, knowledge of AMU and AMR was represented by four survey questions, including a respondent's description of: (i) antibiotic or antimicrobial resistance; (ii) antibiotic or antimicrobial drugs; (iii) antibiotic/antimicrobial withdrawal; and (iv) antibiotic/antimicrobial residues.

To evaluate the association between FFS participation and the three domains, we first coded farmers' responses to each question as '1' indicating a correct response and '0' indicating an incorrect response. Here, 'correct' is defined as knowledge, attitudes, or practices that would be expected to limit the emergence/transmission of AMR, including the prudent use of AMU and observance of IPC practices. See Table 2 for the responses we considered correct and incorrect. After coding responses into correct or incorrect, the number of correct responses was summed and divided by the total number of variables in that area. For example, a person who responded correctly to 15 out of the 21 IPC variables was assigned a score of 71%. Questions concerning animal health seeking practices were not grouped together but were modelled separately. Responses to these questions were either 'yes' or 'no', specifying whether a person first called a veterinarian when their birds were sick or took samples (sick/dead birds) to a laboratory for diagnosis.

Multivariate regression models were used to evaluate the impact of FFS participation on knowledge, attitudes, and practices related to AMU

Table 2. Variables used for scales

Area	Correct	Incorrect
Area 1: KAP related to AMU/AMR: Knowledge variables		
can correctly describe antibiotic or antimicrobial resistance	Yes	No
can correctly describe antibiotics or antimicrobials	Yes	No
can correctly describe antimicrobial withdrawal	Yes	No
can correctly describe what antibiotic residues are	Yes	No
Area 1: KAP related to AMU/AMR: Attitudinal variables		
you can stop giving AMs if animals symptoms are improving	Disagree	Agree/Neutral
if AMs are given too often then they might stop working	Agree	Disagree/Neutral
giving AMs to healthy animals prevents them from becoming sick	Disagree	Agree/Neutral
giving animals AMs can help them grow bigger and faster	Disagree	Agree/Neutral
you should get consultation from a veterinarian before giving AMs	Agree	Disagree/Neutral
after using AMs, you should wait before using products (meat, milk, eggs)	Agree	Disagree/Neutral
using vaccines can prevent the use of AMs	Agree	Disagree/Neutral
Area 1: KAP related to AMU/AMR: Practice variables		
give antibiotics to layers to increase egg production	Never/Rarely	Sometimes/Almost Always
give antibiotics to layers to help them grow faster and bigger	Never/Rarely	Sometimes/Almost Always
give antibiotics to layers to prevent them from getting sick in the future	Never/Rarely	Sometimes/Almost Always
give layers a smaller or larger dose than the recommended	Never/Rarely	Sometimes/Almost Always
stop using medicine before the full treatment because animal improved	Never/Rarely	Sometimes/Almost Always
correct disposal of expired medicines	Yes[a]	No
correct disposal of eggs in withdrawal period	Yes[b]	No
give layers feed supplemented with AMs	Never/Rarely	Sometimes/Almost Always
ask for instructions on use when buying AMs	Almost Always	Sometimes/Never/Rarely
have a prescription when buying AMs	Almost Always	Sometimes/Never/Rarely
Area 2: Animal Health Seeking Practices		
when birds get sick first step is to call veterinarian	Yes	No
when a bird dies, first step is to get laboratory diagnosis	Yes	No
Area 3: IPC Practices		
organize your work from young to older birds (per house)	Almost Always	Sometimes/Never/Rarely
organize your work from healthy to sick birds	Almost Always	Sometimes/Never/Rarely
Treat your litter before using it	Almost Always	Sometimes/Never/Rarely
clean drinkers with soap and or disinfectant	Almost Always	Sometimes/Never/Rarely
clean drinkers daily	Almost Always	Sometimes/Never/Rarely
have a footbath at the layer house entrance	Yes	No
disinfectant present in footbath	Yes	No
footbath dilution immediately changed when visibly contaminated	Almost Always	Sometimes/Never/Rarely
farm is fenced (partially or completely)	Yes	No
own gum boots	Yes	No
own masks	Yes	No
own overalls	Yes	No
PPE cleaned after a few times in the layer house	Almost Always	Sometimes/Never/Rarely
PPE gear only used within the layer house	Almost Always	Sometimes/Never/Rarely
farm workers (other than respondent) wear PPE in the layer house	Almost Always	Sometimes/Never/Rarely
visitors required to wear farm-specific PPE	Almost Always	Sometimes/Never/Rarely
driver/catching team receive farm-specific PPE	Almost Always	Sometimes/Never/Rarely
transport vehicle for spent layers cleaned and disinfected upon arrival	Almost Always	Sometimes/Never/Rarely
dead birds burned or buried after diagnosis	Almost Always	Sometimes/Never/Rarely
use an isolation chamber when a few birds become sick	Almost Always	Sometimes/Never/Rarely

PPE, personal protective equipment; IPC, infection prevention and control.
[a]Correct disposal of expired medicines included incineration or returning to agrovet.
[b]Correct disposal of eggs during withdrawal period was defined as discarding eggs.

Table 3. Self-reported impacts of FFS participation and perceived benefits and challenges[a]

	Ghana ($N=43$)		Kenya ($N=52$)	
	percentage	no.	percentage	no.
FFS On-Farm Impacts				
established footbath	42.6	18	43.1	22
give antibiotics only when birds are sick	83.3	36	41.2	21
improved relationship with veterinarian	51.9	22	31.4	16
clearly demarcated clean area and dirty area	51.9	22	9.8	5
proper record keeping	57.4	25	43.1	22
having visitors log book	33.3	14	5.9	3
keeping to regular hygienic practices	51.9	22	41.2	21
vaccinations at the right time	50.0	22	39.2	20
appropriate spacing of the drinkers and feeders	1.9	1	39.2	20
appropriate number of birds per poultry house	0.0	0	27.5	14
FFS Benefits				
reduced morbidity and mortality	27.8	12	39.2	20
increased egg production compared to previous years	37.0	16	39.2	20
active and healthier birds compared to previous years	11.1	5	31.4	16
more orderly and easy management practices	1.9	1	35.3	18
regulated entrance of farm by visitors	1.9	1	17.6	9
better profits compared to previous years	16.7	7	31.4	16
boosted skills and confidence	NA	NA	43.1	22
FFS Challenges				
not enough time to attend/timing was difficult	44.4	19	27.5	14
people at my farm can't manage when I'm at FFS	14.8	6	9.8	5
the training is too difficult	0.0	0	0.0	0
the training is too expensive	0.0	0	23.5	12

NA, not asked.
[a]Values in the Table represent respondents who replied 'yes' to the statement.

and AMR, and practices involving IPC and animal health seeking. These models controlled for location by entering FFS country as a dummy variable (Ghana = 0, Kenya = 1) and also included factors our previous work demonstrated were related to these three domains in these communities, including gender, age, education level, and farm size.[5,25] For models where the outcome variable was the percentage correct, including knowledge, attitudes, and practices related to AMU and AMR and IPC practices, ordinary least squares (OLS) regression was used because these outcome variables were continuous. Logistic regression was used for the binary outcomes ('yes' or 'no') in the animal health seeking questions. The independent variables included in both OLS and logistic models were whether a respondent had been an FFS participant, country, gender, age, education level, and farm size. See Table S1 for descriptive statistics of independent variables entered into models grouped by country. Results of OLS models are presented as beta coefficients while logistic regression models are presented as odds ratios. Stata 16.1 was used for data cleaning, analysis, and the rendering of figures.[26] Regression diagnostics were run for both OLS and logistic regression models to assess influential points, multicollinearity, specification errors and assumptions of normality of residuals (for OLS). In general, tests indicated assumptions were met. For results and interpretation of OLS regression diagnostics see Tables S2 and S3 and Figures S1 to S10. For results and interpretation of logistic regression diagnostics see Table S4 and Figures S11 to S20.

Ethics

Ethics approvals were obtained in each country. In Kenya, the study was approved by the AMREF Health Africa Ethics and Scientific Review Committee (AMREF-ESRC P551/2018). In Ghana, permission to conduct the study was approved by the Ministry of Health Ethical Review Board (ID No. 014/10/18).

Results

Descriptive statistics for survey sample

There were several demographic differences in survey samples between countries. In Ghana, over 82% ($N=80$) of respondents were male while a majority of respondents in Kenya were female (68%, $N=70$). Kenyan farmers were slightly older (avg. = 49 years, min = 24, max = 82) than Ghanaian farmers (avg. = 42 years, min = 20, max = 68). Education levels were similar between countries, although there were slightly more Ghanaians with tertiary education levels (26.15%, $N=25$) compared with Kenyan layer farmers (15.53%, $N=16$). Differences in farm sizes were also observed across countries. For number of layers owned, the IQR in Ghana was 8000 birds (p25 = 2000, p75 = 8000) and for Kenya was 445 birds (p25 = 155, p75 = 600).

Descriptive statistics specific to FFS

Table 3 provides descriptive statistics on the self-reported changes FFS participants made on their own farms due to FFS participation and the perceived benefits and challenges associated with FFS participation. Across countries, a similar number

Table 4. Results of OLS regression model on AMU/AMR knowledge, attitudes, and practices and IPC practices

Variables	Knowledge	Attitude	Practices	IPC
FFS Participant (1 = Yes, 0 = No)	0.211** (0.131–0.292)	0.141** (0.089–0.193)	0.060** (0.023–0.098)	0.147** (0.111–0.182)
Country (1 = Ghana, 0 = Kenya)	0.078 (−0.060 to 0.216)	0.033 (−0.056 to 0.123)	−0.092** (−0.155 to −0.028)	−0.003 (−0.064 to 0.057)
Age	0.001 (−0.002 to 0.004)	0.001 (−0.002 to 0.002)	0.002* (0.000–0.003)	0.001 (−0.000 to 0.003)
Gender (1 = Female, 0 = Male)	−0.037 (−0.131 to 0.057)	0.027 (−0.034 to 0.088)	0.009 (−0.034 to 0.052)	−0.013 (−0.054 to 0.028)
Education				
secondary Level	0.070 (−0.020 to 0.159)	0.068* (0.010–0.126)	0.004 (−0.038 to 0.045)	0.043* (0.004–0.082)
tertiary Level	0.142** (0.038–0.247)	0.108** (0.040–0.176)	0.063* (0.015–0.111)	0.040 (−0.006 to 0.086)
Farm scale				
medium (400−3000 birds)	0.049 (−0.072 to 0.171)	0.000 (−0.079 to 0.079)	0.006 (−0.049 to 0.062)	0.083** (0.030–0.136)
large (>3000 birds)	0.163* (0.007–0.318)	0.025 (−0.075 to 0.126)	−0.014 (−0.086 to 0.057)	0.101** (0.033–0.168)
Constant	0.456** (0.347–0.565)	0.571** (0.500–0.642)	0.585** (0.535–0.636)	0.342** (0.294–0.390)
Observations	200	200	200	200
R-squared	0.213	0.176	0.224	0.287

95% CIs are shown in parentheses.
*$P < 0.05$;
**$P < 0.01$.

of FFS participants reported outcomes of establishing a footbath, keeping records, and giving vaccinations at the correct times. Compared with Kenyan FFS participants, more Ghanaian participants reported giving antibiotics only when birds were sick and keeping a visitor log-book. For perceived benefits of FFS participation, a similar number of respondents reported the benefits of reduced mortality and increased egg production compared with prior production cycles. More Kenyan participants reported benefits of generally more healthy birds, better regulation of visitors on the farm and better profits compared with previous production cycles. For challenges related to FFS participation, slightly more Ghanaian farmers reported issues with time investment while Kenyan participants were much more likely to report that the training was too expensive.

Comparing FFS and non-FFS

Across Kenya and Ghana, FFS participants scored significantly higher on self-reported scales of AMR/AMU-related knowledge, attitudes, and practices and IPC measures (see Table 4). Relative to non-FFS participants, FFS participants had 21% higher knowledge, 14% higher prudent attitudes, and 6% more prudent practices after controlling for the effects of age, gender, education, and farm size. In addition, individuals with a tertiary education exhibited 14% higher scores on AMU/AMR knowledge, 10.8% higher attitudinal scores and 6.3% higher prudent practice scores. Those with a secondary education exhibited significantly higher (6.8% higher) prudent attitudinal scores while age was significantly associated with prudent practice scores, with every year increase related to a 0.2% increase in practice scores. Those with large farms (>3000 birds) were significantly more likely to report higher knowledge scores (16.8% higher). FFS participants also reported significantly higher IPC scores, with participation associated with a 14.7% higher score compared with non-FFS respondents. Having a secondary level education was associated with a 4.3% increase in IPC practices. Finally, respondents from medium scale farms (400–3000 birds) and large farms (>3000 birds) reported 8.3% and 10.1% higher IPC scores, respectively.

For animal health seeking practices, FFS participants were about five times more likely than non-FFS participants to call a trained animal health professional when their birds became sick, after controlling for demographic effects and farm scale (see Table 5). This significant difference between FFS and non-FFS participants did not extend to taking samples to laboratories for diagnosis. This practice, however, was significantly related to country, with respondents from Ghana associated with a 69% decrease in the odds of reporting taking their sick/dead animals to a laboratory for diagnosis. Taking a sample to a laboratory was significantly associated with gender, with women associated with a 29% increase in the odds of reporting taking their sick/dead birds to a laboratory. Finally, those with a secondary education had an approximately 123% greater odds of reporting taking their birds for laboratory diagnosis.

Discussion

Major findings

AMR is a complex problem requiring complex intervention approaches. Results of the current study suggest that Farmer Field Schools can be effective at addressing the suite of behaviours, both AMR-sensitive and AMR-specific, that drive antimicrobial use and pattern the emergence and transmission of AMR on farms. FFS participants in this study, compared with non-FFS participants, had higher levels of AMU/AMR knowledge and more prudent attitudes and practices, including reporting a reduction, and even elimination, of the use of antimicrobials in layer production. In addition, FFS participants reported greater investments in IPC and were more likely to call an animal health professional upon the first sign of disease in their flocks. These positive effects are consistent with findings that antimicrobial use reductions are most likely to occur when

Table 5. Results of logistic models examining animal health seeking practices

Variables	Call AHP at first sign of sickness	Take sick/dead birds to laboratory
FFS Participant (1 = Yes, 0 = No)	4.97** (3.45–7.15)	1.50 (0.43–5.22)
Country (1 = Ghana, 0 = Kenya)	2.51 (0.82–7.74)	0.31** (0.22–0.44)
Age	1.01** (1.01–1.02)	1.04 (1.00–1.08)
Gender (1 = Female, 0 = Male)	1.01 (0.53–1.93)	1.29** (1.22–1.36)
Education		
Secondary Level	1.36 (0.72–2.56)	2.23** (1.87–2.64)
Tertiary Level	0.84 (0.45–1.57)	0.87 (0.57–1.32)
Farm scale		
Medium (400–3000 birds)	1.14 (0.44–2.95)	1.35 (0.86–2.11)
Large (>3000 birds)	0.83 (0.31–2.23)	1.16 (0.74–1.84)
Constant	0.11** (0.05–0.26)	0.81 (0.41–1.63)
Observations	200	200

95% CIs are shown in parentheses. AHP, animal health professional.
$^{*}P < 0.05$;
$^{**}P < 0.01$.

interventions are co-created in a collaboration between farmers and veterinarians,[27,28] as were current FFS curriculums. Importantly, the positive effects associated with FFS participation remained after controlling for factors that earlier studies have linked to these domains, including demographics, farm size, and geographic location.[5] Some control variables, particularly education level and farm size, also accounted for variance in knowledge, attitudinal, and behavioural domains, particularly biosecurity. The positive association between biosecurity and farm size is consistent with previous work among pig farms in Belgium[29,30] and cattle farms in Sweden[31] suggesting the relationship occurs across high-income and low-and-middle-income settings. In addition, biosecurity research on pig, poultry and cattle farms in Belgium demonstrated consistency across these production systems in the constraints to adopting biosecurity practices, including not having enough information on costs and how biosecurity will impact revenues.[30] While farmers in Ghana and Kenya are likely to face similar constraints, more nuanced examinations of the relationships between farm and farmer characteristics and AMU, AMR and biosecurity practices are needed to develop FFS curriculums tailored to the targeted communities and production systems.

Limitations

Several limitations may impact our study results. First, our cross-sectional design may have produced biased results if FFS participants, compared with non-FFS participants, *initially* had greater AMU/AMR knowledge levels, more prudent attitudes and practices and higher levels of IPC and animal health seeking. To assess this potential source of bias, we conducted a *post-hoc* analysis of our original KAP dataset from 2019. Several respondents from these original studies ($N = 26$) went on to participate in the FFS in Ghana and Kenya. Consequently, we could determine whether these individuals, compared with individuals who did not participate in the FFS, exhibited higher levels of AMU/AMR KAP, IPC and animal health seeking practices. Results of two-group t-tests comparing FFS participants ($N = 26$) with a random selection of non-FFS participants from the original study ($N = 26$) revealed that FFS participants were no more likely to have greater AMU knowledge, prudent attitudes and practices or animal health seeking practices (see Tables S5 to S7). However, original KAP respondents who participated in the FFS did have significantly higher IPC scores. As such, we cannot rule out that some increases attributed to FFS participation were due to participants initially practicing better IPC. A second limitation, and related to biosecurity, is that most behavioural variables, including cleaning of drinkers and personal protective equipment, use of antimicrobials, and animal health seeking were largely limited to self-reported data. More objective measures of these behaviours, including enumerator observation, assessment of farm-records, passive collection of AMU data (e.g. discarding used bottles and packets in trash bins) and triangulation with records of agrovets and veterinarians would provide more robust assessments of the impact of the FFS intervention.

Future studies

Our study results suggest several areas for future investigation. First, there is a need to longitudinally assess the on-farm impacts of FFS participation. The present assessment was conducted immediately after the FFS had concluded so we cannot ascertain the longer-term adoption of FFS lessons. Longitudinal assessments would permit a more sustained assessment of antimicrobial use, IPC, animal health-seeking, and farm profitability, the latter of which is likely the most important for sustained adoption of FFS principles. These studies would benefit from the inclusion of local veterinarians as assessors of FFS graduates. Existing tools, such as the ADKAR® tool, (standing for Awareness, Desire, Knowledge, Ability and Reinforcement) could be used by local veterinarians to assess the barriers to adoption of FFS principles as well as providing a trust-building opportunity between farmer and veterinarian.[32] Results of these studies could provide robust evidence for the positive impacts of FFS, thereby increasing the likelihood that governments, development, and private partners invest in scaling-up FFS as a complex intervention to address AMR. Acquiring 'buy-in' from these partners will be critical as FFS represents a cost-intensive approach to agricultural extension,[33] and some combination of support from these partners and self-funding from FFS participants will be needed to ensure the FFS approach can be sustained and scaled up. Finally, the FFS curriculums should be expanded to emphasize AMR as a One Health issue, for example, through the inclusion of lessons relevant to AMU and AMR in public health. FFSs are well-suited to conveying complex causal relationships, such as those inherent in a One Health approach, due to their emphasis on critical appraisal of the interrelationships between people, their animals, and the environment.

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Transparency declarations

None to declare.

Disclaimer

The views expressed here are those of the authors and do not necessarily reflect the views or policies of the Food and Agriculture Organization of the United Nations.

Supplementary data

Additional statistics, regression diagnostics, post-hoc results, Figures S1 to S20 and Tables S1 to S7, plus the questionnaire are available as Supplementary data at *JAC-AMR* Online.

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