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Factors influencing Scottish dairy farmers' antimicrobial usage, knowledge and attitude towards antimicrobial resistance

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ABSTRACT

Understanding how farmers use antimicrobials and their awareness and beliefs about antimicrobial resistance (AMR) is essential to improve antimicrobial usage (AMU) practices and combat AMR on dairy farms. A cross-sectional online survey was carried out to identify the factors affecting attitudes, knowledge and behaviour of Scottish dairy producers regarding prudent AMU and the emergence of AMR in livestock. The survey was designed based on the earlier findings of two focus groups and was disseminated online via multiple methods (e.g., social media; farming press). Participation was voluntary and answers were obtained from 61 respondents (7.3% of the total population of Scottish dairy farmers). Logistic and ordinal regression analyses were performed to identify predictors for farmers' level of knowledge about antimicrobials and AMR, AMU behaviour and attitudes towards AMR mitigation. Associations were described with odds ratios (OR) and the associated 95% confidence intervals (95% CI). Farmers were more likely to have better knowledge of antimicrobials and AMR if they had undertaken a university degree (OR = 28.28, $P < 0.001$), worked with mixed livestock (dairy plus sheep/beef) (OR = 4.82, $P < 0.05$), and trusted only veterinarians' information about responsible AMU (OR = 4.42, $P < 0.05$). In the survey disease scenarios, younger farmers were less likely to be classed as low antimicrobial users (OR = 0.18, $P < 0.05$) compared to older farmers. Respondents working on larger herds were also less likely to be low antimicrobial users compared to those working on smaller herds (OR = 0.12, $P < 0.01$). Conversely, farmers who did not consider economic factors (e.g., cost and withdrawal period) in antimicrobial choice were more likely to be classed as low antimicrobial users (OR = 6.17, $P < 0.01$). Respondents were more likely to show positive attitudes towards AMR mitigation if they worked in larger (OR = 4.67, $P < 0.05$) or organic dairy farms (OR = 18.35, $P < 0.05$). These results suggest that several practices, social, demographic, and economic factors influence dairy farmers' perception and awareness of AMR and AMU. Efforts should be made to consider these variables when developing strategies to improve AMU in dairy farming. Veterinarians and advisors should focus AMU training and AMR awareness-raising activities towards younger, less experienced farmers as well as those with a lower educational qualification (high school vs. university degree). This study can inform the development of targeted educational initiatives to encourage responsible AMU on dairy farms.

1. Introduction

On dairy farms, antimicrobials are used to treat numerous infectious diseases and are essential to ensure animal health and welfare. Although antimicrobial resistance (AMR) is a complex and multifactorial problem, it has been demonstrated that misuse and overuse of antimicrobials in livestock may contribute to the emergence of resistant bacteria in humans (Tang et al., 2017). For this reason, there is a growing concern about the potential risks and consequences of agricultural antimicrobial usage (AMU) on public health, as the occurrence of antimicrobial-resistant pathogens increases morbidity and mortality and hinders treatment success (Marshall and Levy, 2011).

The World Organisation for Animal Health (OIE), the World Health Organisation (WHO), and the Food and Agriculture Organization of the United Nations (FAO) have made a joint effort to combat AMR globally (White and Hughes, 2019). In the United Kingdom (UK), considerable pressure to restrict livestock AMU has been placed on farmers and veterinarians over the last decade (O'Neill, 2016). Recently, the

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government issued the last UK five-year national action plan, “Tackling antimicrobial resistance 2019–2024”, which focuses primarily on reducing the need for antimicrobials through good animal husbandry, disease prevention, and biosecurity (Courtenay et al., 2019). Guidelines for responsible AMU have been produced by the Responsible Use of Medicine in Agriculture Alliance (RUMA) and are addressed to farmers across all sectors (RUMA, 2015).

In the UK, dairy farmers can keep a supply of prescribed antimicrobials on-farm and they often make individual animal treatment decisions without the supervision of a veterinarian (Higham et al., 2018). Farm AMU can be estimated through veterinary practices’ sales data and on-farm medicine records, with the first method being the most accurate (Rees et al., 2021). Despite quantifying and monitoring of AMU at the farm-level being essential to implement AMR stewardship measures and track progress, it cannot capture farmers’ AMU decision-making and intentions to reduce AMU. Elucidating what influences farmers’ AMU and attitudes towards AMR mitigation is a crucial step for developing strategies and tackling AMR on dairy farms.

Some sociological models demonstrate that human behaviour is strongly influenced by knowledge and attitudes towards the behaviour (Ajzen, 1991). In the UK, surveys showed that knowledge of antimicrobials and AMR varies considerably among dairy farmers. For instance, approximately 50% of farmers were unable to provide an accurate description of AMR (Higham et al., 2018), and 34% were not aware of the inappropriate usage of the highest priority critically important antibiotics (HP-CIAs) as first-choice antimicrobials (Jones et al., 2015). Several studies have demonstrated that enhanced farmers’ knowledge of antimicrobials and AMR is associated with prudent AMU (McKernan et al., 2021). Education provision, however, is often insufficient to invoke behavioural changes and needs to be integrated with a clear understanding of other factors, such as beliefs, perceptions and values. Ritter et al. (2017) described that the uptake of guidelines and best practice recommendations is influenced by the demographic factors and personal background of dairy producers. In addition, farmers’ behaviour is greatly shaped by the political and economic context in which they live, such as milk price and retailer policies (Bard et al., 2019; Skjølstrup et al., 2021). Overall, UK dairy farmers showed positive attitudes to decrease AMU, but many questioned their ability to achieve this goal (Golding et al., 2019; Jones et al., 2015). Furthermore, they usually do not perceive AMR as a current threat to their farms (Helliwell et al., 2019). Studies carried out in various countries have demonstrated the existence of a positive association between dairy farmers’ attitudes and behaviour related to AMU reduction (Speksnijder and Wagenaar, 2018; Farrell et al., 2021). For instance, producers showing positive attitudes were more likely to implement selective dry cow therapy (SDCT), as opposed to blanket antimicrobial treatment at dry-off (Scherpenzeel et al., 2016).

The evidence suggests that recognising the factors associated with farmers’ AMR knowledge and positive attitudes may help to encourage behavioural change to reduce AMU and preserve antimicrobial effectiveness. Therefore, this study aims to identify farm characteristics, demographic and social factors influencing Scottish dairy farmers’ AMU behaviour, knowledge of antimicrobials and AMR and attitudes towards AMR mitigation. The second objective of the study was to determine the association between farmers’ knowledge, attitude, and behaviour towards AMU and AMR.

2. Materials and methods

2.1. Survey design and distribution

A cross-sectional study was conducted among Scottish dairy producers using an online survey between the 26th of April and the 31st of August 2021, which was devised using an Online Surveys tool (JISC survey). The survey URL was disseminated in multiple ways (via the farming press, social media, veterinary practices, and milk buyers). The target population included all Scottish dairy farmers (n = 832) and participation was voluntary. Inclusion criteria were working on a Scottish dairy farm and being responsible for antimicrobial administration. Participants were provided with a *Participant Information and Consent Form* (PICF) at the beginning of the survey. Participation was anonymous and no personal information was collected, however, as an incentive, respondents could disclose their e-mail address to participate in a prize draw to win one of four £ 25 Lidl vouchers. The research gained ethical approval from the local ethics university committee (project number 200200070).

The survey design was guided by previous results from a focus group and a workshop. The focus group was held in August 2020 and included a convenience sample of dairy farmers known by the author (n = 5). The workshop was held in November 2020 as part of an online agricultural event (Agriscot) and consisted of multiple poll questions presented to online participants (approximately n = 40). As a result of the COVID-19 pandemic, they were both conducted remotely. The current survey was piloted by five farmers known by the authors to test the duration and clarity of the questions.

The topics explored during the focus groups and the survey structure have already been described in detail in a previous publication (Borelli et al., 2022). The survey included 54 main questions (33 multiple choices, 13 Likert scale, five matrix, four open-ended, and one ordinal) and consisted of four sections (Appendix I). The first section explored farmers’ knowledge and understanding of antimicrobials and AMR, their awareness of guidelines for responsible AMU and the importance and contact with some social referents (e.g., veterinarian, milk buyer, other farmers). The second section collected information about farmers’ AMU and implementation of responsible practices (e.g., AMU treatment protocols, SDCT), including some common clinical scenarios encountered in dairy farms (e.g., clinical mastitis; metritis; calf diarrhoea and pneumonia; lameness; drop in milk yield). The third section assessed farmers’ attitudes and concerns regarding AMR on UK dairy farms using five-point Likert scale statements. The final section collected demographic information (e.g., age, sex, level of education, role on the farm) and herd details (herd size, average milk production, organic or conventional system). With the exclusion of the name of the milk buyer, it was required to answer all questions to submit the survey. The antimicrobials considered in this study refer to all types of antibiotics used in dairy farming.

2.2. Statistical analysis

Survey answers were downloaded and organised in a datasheet in Microsoft Excel 2010 (Microsoft Corporation, Redmond, Washington, USA). All statistical analyses were performed using R studio with R version 4.2.0 (http://www.r-project.org/). Sample herd size, milk production and average somatic cell counts (SCC) were analysed to ensure they were representative of the target population of Scottish dairy farms using the Two-sample Kolmogorov-Smirnov test. Reference herd size data were obtained from the Scottish Dairy Cattle Association, while SCC and milk yield information was provided by the Cattle Information Service (CIS) in Scotland. Associations between the three outcomes of interest (farmers’ antimicrobial and AMR knowledge, AMU behaviour and attitude towards AMR) and predictors were explored with separate regression models.

2.2.1. Definition of the outcome variables: Knowledge, AMU behaviour, and attitude

The three main outcomes of interest of the study were farmers’ knowledge of antimicrobials and AMR, AMU behaviour, and attitude towards AMR mitigation (Table 1). Respondents’ knowledge was defined by the number of correct responses to three questions (Appendix I; Q 2–4). Free-text responses to “What does antibiotic resistance mean to you in your own words?” were defined as correct (score = 1) only when referable to “bacteria develop resistance and do not respond to

Table 1
Outcome variables for the three regression models exploring Scottish dairy farmers' knowledge, behaviour and attitude towards antimicrobial usage and resistance.

Outcome variable	Question number used to assign score	Score distribution N (%[a])	Categorised score N (%)
Knowledge	Score: 0 =incorrect; 1 =correct Q 2: What does "Antibiotic resistance" mean to you in your own words? Q 3: In your opinion, are antibiotics effective against the following pathogenic organisms? Correct option = bacteria Q 4: What effects do antibiotics have? Correct option = anti-bacterial	Tot. score 0: 14 (23%) Tot. score 1: 16 (26%) Tot. score 2: 24 (39%) Tot. score 3: 7 (12%)	Unsatisfactory knowledge: 30 (49%) Satisfactory knowledge: 31 (51%)
Behaviour	Score: 0 =AM used; 1 =no AM used What would you do first in the following clinical case? Q 25: Milking cow: sign of mild mastitis (milk modified, udder inflamed, no fever, no systemic signs) Q 26: One-week old calf: diarrhoea, no fever, slightly dehydrated, normal appetite Q 27: Cow: 10 days post-partum, smelly uterine discharge, temperature 39.5 C Q 28: Six calves aged 1–2 months: cough, nasal discharge, fever Q 30: Milking cow: sudden lameness in one hind limb Q 31: Milking cow: sudden milk drop and fever (T: 39.9 °C)	Tot. score 0: 3 (5%) Tot. score 1: 12 (20%) Tot. score 2: 17 (28%) Tot. score 3:16 (26%) Tot. score 4: 11 (18%) Tot. score 5: 2 (3%) Tot. score 6: 0 (0%)	High user: 15 (25%) Medium user: 33 (54%) Low user: 13 (21%)
Attitude	Score: 1 =strongly disagree; 2 =disagree; 3 =neither disagree nor agree; 4 =agree; 5 =strongly agree To what extent do you agree with the following statements? Q 32: It is important to reduce AMU on UK dairy farms Q 33: Nowadays, there is too much reliance on AMU in UK dairy farms Q 34: Decreasing AMU in dairy farms could help reducing AMR in livestock Q 35: Decreasing AMU in dairy farms could help reducing AMR in humans Q 44: I am worried about AMR on UK dairy farm	Av. Score 2.5–3.0: 8 (13%) Av. Score 3.1–3.4: 8 (13%) Av. Score 3.5–4.0: 25 (41%) Av. Score 4.1–4.4: 9 (15%) Av. Score 4.5–5.0: 11 (18%)	Neutral attitude: 16 (26%) Positive attitude: 34 (56%) Very positive attitude: 11 (18%)

Notations: AM = Antimicrobial; AMU = Antimicrobial usage; AMR = Antimicrobial resistance; UK = United Kingdom
[a]Percentages were rounded to two decimal places. This caused some numbers to not add up to 100%.

some antimicrobials". Other definitions reported (e.g., "animals developing AMR", "antimicrobials losing efficacy") were considered incorrect (score = 0). The two multiple-choice questions were assigned a score 1 (correct) or 0 (incorrect) as described in Table 1. The total knowledge score, ranging from 0 to 3, was converted into a binary variable using the median as a cut-off: "Unsatisfactory knowledge" (score 0–1) and "Satisfactory knowledge" (score 2–3).

Farmers' AMU behaviour was determined through six clinical disease scenarios (Appendix I; Q 25–28;30–31). For each clinical case, respondents were asked whether they would administer an antimicrobial (score = 0) or whether they would first take an alternative action (e.g., anti-inflammatory, consult the veterinarian, collect a sample, monitor the animal; score = 1). Total AMU score, ranging from 0 to 5, was further categorised into three levels based on equal intervals: "low user" (scores 4–5), "medium user" (scores 2–3), and high user (scores 0–1).

Farmers' attitudes towards AMR mitigation were determined by averaging the degree of farmers' agreement/disagreement with five-point Likert scale statements regarding AMR (Appendix I; Q 32–35;44). The Cronbach alpha value of all statements was 0.80, indicating acceptable internal reliability. The Likert scale responses were scored from 1 to 5, (from 1 = strongly disagree to 5 = strongly agree) and then averaged. The average attitude score, ranging from 2.5 to 4.8, was further categorised into three levels based on the nearest Likert scale point: neutral attitude (average score between 2.5 and 3.4), positive attitude (average score between 3.5 and 4.4), and "very positive attitude" (average score ≥ 4.5). No negative attitudes were expressed by farmers.

2.2.2. *Definition of the predictor variables*

Predictor variables considered relevant for the three outcomes and included in the models were: farmers' demographics and farms' characteristics, self-reported guidelines awareness and source information used about prudent AMU, the occurrence of vet discussion about AMR, the presence of protocols on farms, antimicrobial decision-making, and self-reported AMU change. Level of knowledge was included as a covariate in the AMU behaviour and attitude models, and so was the level of attitude in the AMU behaviour model (Ajzen, 1991). Herd size (number of milking cows) was not normally distributed (Shapiro test, $P > 0.05$) and was log-transformed to achieve normality. The four categories of RUMA guideline familiarity (Appendix I, Q 5–5.a) were combined into three levels: low (never heard or not familiar), medium (somewhat familiar), and high familiarity (very familiar). Responses to two matrix questions (Appendix I, Q 10;18) were analysed to identify types of respondents with similar characteristics and used as predictor variables. The two questions explored the main sources of AMU information considered and the main factors influencing antimicrobial choice. Each response option was assigned a score from 1 (not used/considered) to 4 (used/considered with high confidence/importance), and then farmers were divided into K clusters based on their ratings (K-means method). Each cluster was represented by the mean of the data points belonging to it.

2.2.3. *Statistic regression analysis*

One logistic (farmer's knowledge) and two separate ordinal regression (farmer's AMU behaviour and attitude) models were built. Independent variables associated with the outcomes by bivariate analysis ($P < 0.2$) were included in the regression analysis. The final models were obtained via the stepwise backward elimination process using the likelihood ratio test and the Akaike information criterion (AIC). The presence of confounding variables was evaluated based on a more than 20% difference in the OR between the estimate in the model with the variable controlled for and the estimate in the model with the variable removed. The Variance Inflation factor (VIF) was used to test collinearity between variables. Finally, the Hosmer-Lemeshow test was applied to test model fit. Results were expressed as odds ratio (OR) and the associated 95% confidence interval (CI). Statistical significance was established at p-value < 0.05.

3. Results

In total, 61 respondents completed the survey. According to the Scottish Dairy Cattle Association, there were 832 dairy farms in 2021 (Farm Advisory Service, 2022), therefore responses accounted for 7.3% of the target population. All versions were answered completely, and none were excluded from the analysis. General descriptive statistic results from this survey are available in the previous paper (Borelli et al., 2022). The sample population was found to be representative of the target population (Scottish dairy herds) in herd size, milk yield and SCC (P > 0.05, Two-sample Kolmogorov-Smirnov test).

3.1. K-mean clusters for AMU source of information and decision-making

Based on their response to two matrix questions (source of AMU information considered; factors influencing antimicrobial choice), respondents were clustered into groups. Clusters were labelled based on their dominant pattern of behaviour.

Farmers in the cluster "Vet info" trust with high confidence only information from veterinarians about responsible AMU (other sources' mean score was below 2, meaning that they are used with low confidence or not used); respondents in the cluster "Vet and other info" reported using with relative confidence information from sources other than veterinarian (Table 2).

Farmers in the cluster "Vet and experience" consider mainly veterinarian advice and personal previous experience for antimicrobial decision-making, whilst farmers in the "Economic" cluster also consider economic factors such as cost and withdrawal period (Table 2).

3.2. Farmers' knowledge of antimicrobials and AMR

Table 3 shows the predictor variables used for the model of farmers' knowledge of antimicrobials and AMR. The final logistic regression results are presented in Table 4. Respondents holding a university degree had 28.28 times higher odds of showing satisfactory knowledge than respondents with a lower educational level (95% CI = 4.72–169.35; P < 0.001). The odds of expressing satisfactory knowledge were 4.42 times higher when respondents considered only veterinarians as reliable sources of information for responsible AMU (95% CI = 1.04–18.13; P < 0.05). Farmers breeding other livestock had better knowledge than farmers working with dairy cows only (OR = 4.82; 95% CI = 1.19–19.47; P < 0.05). The Hosmer-Lemeshow test was not significant (P = 0.303) suggesting that the model fit the data well.

3.3. Farmers' AMU behaviour

Table 3 shows the predictor variables used for the model of farmers' AMU behaviour. The final ordinal regression model results are presented in Table 4. In the clinical scenario section, younger farmers (<35 years old) were significantly less likely to be low users of antimicrobials when compared to farmers older than 51 years (OR = 0.18; 95% CI = 0.03–0.85; P < 0.05). Respondents working in larger farms were also less likely to be low users of antimicrobials (OR = 0.12; 95% CI = 0.02–0.62; P < 0.01). The odds of showing low AMU were 6.17 times higher for farmers basing their antimicrobial choice only on veterinarian advice or previous experience, compared with farmers also considering economic factors (95% CI = 1.81–21.01; P < 0.01). Producers who reduced their AMU in recent years were 8.87 times more likely to be classified as low user of antimicrobials (95% CI = 1.18–66.31; P < 0.05). Farmers' AMU was not affected by their knowledge and attitudes towards AMR. The Hosmer-Lemeshow test was not significant (P = 0.892) suggesting that the model fit the data well.

3.4. Farmers' attitudes towards AMR

Table 3 shows the predictor variables used for the model of farmers' attitudes towards AMR. The final ordinal regression model results are presented in Table 4. Compared to conventional herds, organic farm producers had 18.35 times higher odds of showing a very positive attitude towards AMR mitigation (95% CI = 1.58–216.64; P < 0.05). In addition, the odds of having a more positive attitude were higher for farmers working in a larger herd (OR = 4.67; 95% CI = 1.04–21.01; P < 0.01). Farmers' role was retained in the model as a confounder, as its removal resulted in a change of more than 20% of the farm size coefficient. Farmers' attitudes were not associated with their level of knowledge of antimicrobials and AMR. The Hosmer-Lemeshow test was not significant (P = 0.579) suggesting that the model fit the data well.

4. Discussion

Antimicrobial resistance has been described as one of the most severe global threats of this century (World Health Organisation, 2021). Since the transmission of antimicrobial-resistant microorganisms between animals and humans has been documented (Tang et al., 2017), AMU in agriculture and farmers' beliefs towards AMR have gained particular attention in recent years. This study provides insight into the factors driving knowledge, behaviour, and attitudes of dairy farmers towards AMU and AMR in Scotland.

Respondents holding a university degree demonstrated better knowledge of antimicrobials and AMR. This association, which was reported by other studies carried out in different countries (Alhaji et al., 2019; Ozturk et al., 2019; Dankar et al., 2022), likely results from increased comprehension of the mechanisms behind antimicrobial activity and bacteria resistance among respondents with higher education attainment. Despite risk perception being complex and related to several factors, farmers' misconceptions about AMR may lead to the underestimation of its threat and drive antimicrobial misuse (Skjølstrup et al., 2021). For this reason, veterinarians and advisors should prioritise regular training on AMU and AMR for farmers with a lower level of education, as improving farmer awareness has been demonstrated to encourage responsible AMU across all farm sectors (McKernan et al., 2021). Despite exact figures not being available, it is believed that

Table 2
K-means clusters[1] of the factors influencing antimicrobial choice and the sources of antimicrobial usage information considered by Scottish dairy farmers'.

Source of AMU information Hopkins value = 0.6	Veterinarian	Milk buyer	Web	Other farmers	Farming articles
Vet info (n = 28)	4	1.5	1.5	1.6	1.2
Vet and other info (n = 33)	3.9	3.3	2.5	2.6	2.6
Antimicrobial choice Hopkins value = 0.7	Antimicrobial cost	Withdrawal period	Previous usage experience	Veterinarian advice	
Vet and experience (n = 31)	1.54	2.61	3.96	3.84	
Economic (n = 30)	3.03	3.73	3.90	3.83	

Notation: AMU = Antimicrobial usage
[1]The optimum number of clusters was defined a priori with the fviz_nbclust() function in R; a bend (knee) in the plot indicates the appropriate number of clusters. Visual method and the Hopkins statistic were applied to assess the clustering tendency of the dataset

Table 3
Predictor variables considered for three regression models exploring Scottish dairy farmers' knowledge, behaviour and attitude towards antimicrobial usage and resistance.

Predictor variables (Question number)	N (%[a])	Models including the predictor		
		Knowledge	Behaviour	Attitude
Familiarity with RUMA guidelines (Q 5.a)				
Low	10 (16%)	X[b]	X	X
Medium	39 (64%)			
High	12 (20%)			
Discussion with vet about AMR (Q 9)				
Yes	56 (92%)	X	X	X
No	5 (8%)			
Source of AMU information used (Q 10)				
Vet info	28 (46%)	X		X
Vet and other info	33 (54%)			
AMU protocols on farm (Q 15)				
Yes	41 (67%)		X	
No	20 (33%)			
Antimicrobial choice (Q 18)				
Vet and experience	31 (51%)		X	
Economic	30 (49%)			
AMU change last years (Q 21)				
Less	55 (90%)		X	
Same	6 (10%)			
Age (Q 45)				
< 35 years old	13 (21%)	X	X	X
36–50 years old	28 (46%)			
> 51 years old	20 (33%)			
Sex (Q 46)				
Male	55 (90%)	X	X	X
Female	6 (10%)			
Highest level of education (Q 48)				
Secondary school	41 (67%)	X	X	X
University	20 (33%)			
Farm system (Q 49)				
Conventional	57 (93%)	X	X	X
Organic	4 (7%)			
Log Farm size (Q 50)	-	X	X	X
Livestock farmed (Q 53)				
Only dairy	32 (52%)	X	X	X
Other livestock (beef/sheep)	29 (48%)			
Role on farm (Q 54)				
Employee	17 (28%)	X	X	X
Owner	44 (72%)			
Knowledge (Table 2)				
Satisfactory	31 (51%)		X	X
Unsatisfactory	30 (49%)			
Attitude (Table 2)				
Neutral	16 (26%)		X	
Positive	34 (56%)			
Very positive	11 (18%)			

Notations: RUMA = Responsible Use of Medicine in Agriculture Alliance; AMU = Antimicrobial usage; AMR = Antimicrobial resistance
[a]Percentages were rounded to two decimal places. This caused some numbers to not add up to 100%
[b]"X" indicate the regression models the where predictor was included

Table 4
Final regression analysis of factors associated with increased knowledge about antimicrobials and antimicrobial resistance, low antimicrobial usage (in the survey clinical disease scenarios), and positive attitudes towards antimicrobial resistance mitigation among 61 Scottish dairy farmers.

Predictor of farmers' knowledge (logistic regression)	Coeff	SE	OR	OR 95% CI	P value
Education degree					
Secondary school	Referent	0.89	-	-	-
University	3.34		28.28	4.72–169.35	< 0.001
Source of AMU information used					
Vet and other info	Referent	0.78	-	-	-
Vet info	1.47		4.42	1.04–18.13	< 0.05
Livestock farmed					
Only dairy	Referent	0.69	-	-	-
Other livestock (beef/sheep)	1.57		4.82	1.19 – 19.47	< 0.05
Predictor of farmers' AMU behaviour (ordinal regression)	**Coeff**	**SE**	**OR**	**OR 95% CI**	**P value**
Age					
> 51	Referent	-	-	-	
36–50	-0.36	0.64	0.69	0.19–2.54	0.57
< 35	-1.71	0.77	0.18	0.03–0.85	< 0.05
Farm size (Log10-transformed)	-2.10	0.81	0.12	0.02–0.62	< 0.01
Antimicrobial choice					
Economic	Referent	-	-	-	-
Vet and experience	1.82	0.61	6.17	1.81–21.01	< 0.01
AMU change last years					
Same	Referent	-	-	-	-
Less	2.18	1.00	8.87	1.18 – 66.31	< 0.05
Predictor of farmers' attitude (ordinal regression)	**Coeff**	**SE**	**OR**	**OR 95% CI**	**P value**
Farm type					
Conventional	Referent	1.22	-	-	-
Organic	2.91		18.35	1.58–216.64	< 0.05
Farm size (Log-transformed)	1.54	0.75	4.67	1.04–21.01	< 0.05
Role					
Employee	Referent	-	-	-	-
Owner	0.77	0.59	2.16	0.65 – 7.19	0.196

Notation: AMU = Antimicrobial usage

producers holding higher academic qualifications represent a small proportion of the Scottish dairy sector. Therefore, encouraging people with a higher level of education to be involved in dairy farming may improve the awareness of AMR and facilitate judicious AMU. This could be achieved through proactive school programs demonstrating the opportunities in agriculture. In addition, the dairy industry and farmers' organisations should collaborate to shift misconceptions about farming, provide better economic returns and offer higher-quality work conditions, in order to bring qualified and knowledgeable workforces into the dairy industry.

Interestingly, respondents breeding livestock other than dairy cows (e.g., beef and sheep) expressed better AMR and AMU knowledge than dairy-only farmers. Farmers working with other livestock may be exposed to different AMR education campaigns and to different advisors, contributing to their improved awareness. Sheep farmers are also dealing with the current emergence of anthelmintic resistance which might enhance their general comprehension of drug resistance.

In our survey, veterinarians were considered as the most trustworthy source of information and farmers using with confidence "only veterinarian information" had greater knowledge than farmers also relying on other sources. The importance of veterinarians' role in raising AMR awareness has already been highlighted in a number of other studies (Friedman et al., 2007; Jones et al., 2015; Swinkels et al., 2015; Golding et al., 2019; Doyle et al., 2022). However, due to time constraints, concerns of being intrusive and farmers' reluctance to change AMU practices, veterinarians may struggle to play a proactive role in the fight against AMR (Speksnijder and Wagenaar, 2018; Llanos-Soto et al., 2021; Gröndal et al., 2023). Also, in a recent review it was described that dairy farmers desire a more reciprocal relationship of trust with their veterinarian (Farrell et al., 2021), while others expressed the need for homogenous messages from advisors, as they often receive conflicting information on AMU (Speksnijder et al., 2015). Thus, in order to facilitate prudent AMU, it is important for veterinarians to build relationships with farmers based on trust and shared understanding. Workshops and discussion sessions are seen by UK practitioners as efficient tools to disseminate AMU knowledge and build successful veterinarian-farmer collaboration (Higgins et al., 2017).

Regarding the AMU behaviour, young producers (<35 years old) reported higher AMU in the scenarios compared to their older colleagues. The unpredictable nature of the infectious disease in dairy cattle and the concern about the potential cost associated with animal losses may lead inexperienced young farmers to administer antimicrobials as a risk-avoidance strategy. In contrast, older farmers might be more circumspect and prone to try alternative approaches.

Higher AMU was also reported by respondents expressing greater consideration for economic factors in antimicrobial choice (e.g., antimicrobial withdrawal period and cost). Likely, different financial situations affect how antimicrobials are used on farms. Tight profit margins and economic constraints have previously been described as significant barriers to reducing AMU (Jones et al., 2015; Ekakoro et al., 2019), and farmers feared that not administering antimicrobials would reduce profitability and revenues (Orpin, 2017). It is possible that producers facing financial difficulties base their AMU choice on enhancing productivity rather than fighting AMR. Then, it is important for veterinarians and advisors to consider the economic situation of each farm and deliver tailored advice. Simple and low-cost hygiene/management practices to reduce the need for AMU may be more easily implemented by farmers with low economic means. It is also crucial to make them aware of the feasibility of maintaining farm profitability with limited AMU.

Another factor associated with greater AMU in the scenarios was larger farm size. Labour burden and time constraints, which usually occur in large herds, have been previously identified as significant barriers to reducing AMU (Friedman et al., 2007; Speksnijder et al., 2015; Scherpenzeel et al., 2016; Golding et al., 2019). Having sick animals is time-consuming and interrupts the daily routine, thus administering antimicrobials may be regarded as an easier and faster solution than monitoring and providing alternative care (e.g., comfortable housing and environment conditions and isolation from other animals). On the other hand, we found that respondents working in large dairy herds expressed greater intentions to reduce AMU and fight AMR. As previously suggested, it is possible that the higher financial resources of these farmers shape their perceived ability to tackle AMR (Fischer et al., 2019). A more positive attitude may be also associated with the intention to avoid potential future restrictions on AMU which would greatly challenge big herds.

In a recent UK study, conventional farmers reported higher HP-CIAs usage than organic farmers, likely due to the restrictions existing for the organic industry (Regulation No 889/2008/EC) (Higham et al., 2018). Despite our results showing no difference in AMU behaviour between the two production systems, we found that organic farmers expressed more positive attitudes than conventional farmers in relation to AMU and AMR. This finding might reflect an ethical responsibility to produce milk free of antimicrobial residues and a desire to meet consumers' perception of organic farming (Clark et al., 2016). On the other hand, it is possible that farmers with particular interests or attitudes are more likely to be involved with organic production systems.

In contrast with other authors (Jones et al., 2015; Ritter et al., 2015; Scherpenzeel et al., 2016), we did not find any association between dairy farmers' antimicrobials and AMR knowledge and their attitudes or AMU behaviour. In other words, respondents with greater awareness of AMR did not display lower AMU nor a more positive attitude to reduce their reliance on antimicrobials. It is possible that farmers face difficulties putting their knowledge into practice and implementing recommended changes. Translating technical knowledge into action may be challenged by limited resources, such as proper stockmanship, finances and farm facilities. In addition, lack of support, and concerns about animal welfare may negatively influence producers' motivation to reduce AMU (Speksnijder and Wagenaar, 2018; Farrell et al., 2021). Although many external factors might hinder the relationship between knowledge, attitude and behaviour, raising awareness among producers is likely the first step to fighting AMR. Indeed, farmers are less willing to invest their time and resources in issues that are not perceived as threatening their everyday reality (Ritter et al., 2017).

This study has several strengths and limitations. To the best of our knowledge, this is the first study investigating these aspects in the Scottish dairy sector. We have identified some potential drivers for farmers' uptake of best practices and behavioural change related to reduced AMU. However, many of the results were self-reported, so caution should be taken when interpreting these findings due to social desirability bias. Social desirability may have been limited by the voluntary and anonymous basis of participation in the survey. Despite representing a good proportion of the total population of Scottish dairy farmers (7.3%), the absolute number of responses is low and this is reflected in the large 95% CIs. The low response rate may be due to fatigue and time pressures felt by producers. Also, increased pressure on AMR and reducing AMU from government bodies, the dairy industry and the media may result in a reluctance to share opinions. Self-selection bias due to voluntary participation was possible and a particular interest in the subject of AMU and AMR for farmers who answered the survey may have introduced potential bias. Among the respondents, 33% held a university degree. We were unable to access data to assess whether the educational level of respondents was representative of Scottish dairy farmers, however, it is possible that respondents with higher school degrees were overrepresented in this survey.

5. Conclusions

This survey provides insights into the factors influencing Scottish dairy farmers' knowledge and perceptions of AMR and AMU in dairy farming. The results highlighted the importance of veterinarians in raising AMR knowledge and guiding AMU choices. Some demographic factors, such as level of education and age, were associated with farmers' AMU and AMR knowledge and should be considered by veterinarians and advisors when encouraging behaviour change. Also, farm systems (organic vs. conventional) and size affected farmers' AMU and attitudes and intentions to combat AMR on dairy farms. These results did not show any association between antimicrobial and AMR knowledge and positive intentions to reduce or reduced AMU behaviour.

Declaration of Competing Interest

The authors have no conflicts of interest to declare. All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

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Appendix

1. I confirm that I have read and understood the Participant Information Sheet and I consent to the data to be collected and used as described
2. What does "Antibiotic resistance" mean to you in your own words? (Open question)
3. In your opinion, are antibiotics effective against the following pathogenic organisms: viruses, bacteria, and parasites? Tick one option for each pathogen
   ○ Not effective at all
   ○ Somewhat effective
   ○ Very effective
   ○ Don't know
4. What effects do antibiotics have? (Tick all that apply)

o Analgesic (reduce pain)
o Anti-inflammatory (reduce inflammation)
o Antipyretic (reduce animal's temperature)
o Anti-bacterial (kill or inhibit bacteria causing the infection)
o Other

5. Have you ever heard of the RUMA (Responsible Use of Medicine in Agriculture) guidelines for the responsible usage of antibiotics in cattle production?

○ Yes

o No

5.a. If yes, how familiar are you with the guidelines?

o Not familiar at all
o Somewhat familiar
o Very familiar

6. Over the last month, how many times did you see your vet for a routine visit (e.g. fertility, foot trimming/mobility scoring, disbudding, calves check etc.)

o Never
o Once
o More than once
o Once every week or more

7. Over the last month, how many times did you see your vet for an emergency or non-routine visit (e.g. calving, milk drop, pneumonia, lameness, mastitis, sick calf etc.)?

o Never
o Once
o More than once
o Once every week or more

8. How often do you consult your vet before using an antibiotic?

○ Never

o Sometimes
o Most of the time
o Always

9. Have you ever spoken with your vet about antibiotic resistance?

o Yes
o No

9.a. If yes, how often do you speak about it approximately?

o Annually
o Every six months
o Monthly
o At every visit

10. Have you ever sought advice on antibiotic usage from any of the following sources and how confident are you in the information you received: farming articles, other farmers, web, milk buyer, veterinarian? Tick if the following sources are used and the level of confidence in them

o Not used
o Used with low confidence
o Used with medium confidence
o Used with high confidence

11. How important to you is the opinion of the following people around antibiotic reduction: veterinarian, other farmers, milk buyer, consumers, colleagues, family? Tick the degree of importance for each person/people

o Not important
o Somewhat important
o Very important

12. Which is your most frequently used antibiotic?

o Penicillin/Amoxycillin
o Oxytetracycline
o Tylosin
o Ceftiofur
o Other

13. Which of the following diseases is the main reason for antibiotic usage on your farm? Rank them from 1 to 6, with 1 being the most common reason for usage and 6 being the least

o Mastitis
o Calf pneumonia
o Calf scour

o Lameness
o Post-partum diseases
o Dry cow therapy

14. Do you have any practices in place on your farm to reduce the usage of antibiotics?

o Yes. Which practices do you use? (Open question)
o No

15. Do you have written protocols regarding the choice of antibiotics on farm?

o Yes
o No, but I am considering developing it in the future
o No, and I do not intend to do it

16. What is the most important reason for calling the vet when you have a sick animal?

○ Economic value of the animal

o Previous treatment unsuccessful
o Several animals involved
o Animal welfare
o Others

17. What is the main reason for not calling the vet when you have a sick animal?

○ Cost

o Delay in treating animals
o Vet visit means additional work
o I have enough experience
o Others

18. Which factors do you consider important when choosing an antibiotic: cost, vet advice, previous experience, withdrawal period? Tick which factors you consider and the related level of importance for you

o Not considered
o Considered with low importance
o Considered with medium importance
o Considered with high importance

19. How frequently do you send samples for culture and sensitivity (milk, faeces, nasal swabs) before using antibiotics?

o Never
o Occasionally
o Regularly

19.a. If answered never or occasionally, why?

o Too expensive
o It takes time before having the results
o I am not sure about the benefit
o Inconclusive results occur too often
o Other

20. Do you use selective dry cow therapy on your farm?

o Yes. In which approximate percentage of milking cows do you use antibiotics?
o No, but I am considering doing it in the future
o No, and I do not intend to do it

21. How has antibiotic usage on your farm changed over the last few years?

o Less
o Same
o More

21.a. If your antibiotic usage has decreased, was it difficult?

o Yes. Which were the main barriers? (Open question)
o No
o I do not know

12.b. If your antibiotic usage did not change, do you think it would be difficult to reduce it?

o Yes. What are the main barriers? (Open question)
o No
o I do not know

22. How do you expect your antibiotic usage to change over the next five years?

o Less
o Same
o More

23. How much would the following factors influence your decision to reduce antibiotic usage on farm: reduced antibiotics cost, reduced animal antibiotic resistance, reduced human antibiotic resistance, minimise the risk of antibiotic residues in milk, meet milk buyer standards, more consumer confidence? Tick the degree of influence for each factor

o No influence
o Some influence
o A lot of influence

24. How much do the following factors concern you about reducing antibiotic usage on farm: increased animal disease/death, decreased profitability, decreased milk production, reduced animal welfare, increased costs (e.g., new facilities required)? Tick the degree of concern for each factor

o Not concerning
o Somewhat concerning
o Very concerning

25. Scenario 1: Milking cow: sign of mild mastitis (milk modified, udder inflamed, no fever, no systemic signs)

25.a. What would you do first?

o Call the vet
o Administer an intramammary antibiotic tube. Which one? (Open question)
o Administer a systemic antibiotic. Which one? (Open question)
o Take a milk sample for culture
o Monitor the cow
o NSAIDS/fluids
o Other

25.b. If you treat the cows with antibiotics, where would you record the treatment? (Tick all that apply).

- o I do not record
- o Treatment book
- o Mark the cow
- o Computer
- o Other

25.c. If you treat the cows with antibiotic, what do you do with the milk?

- o Throw it away
- o Feed to all calves
- o Feed to some calves but not replacement heifers
- o Other

26. Scenario 2: 1-week-old calf: diarrhoea, no fever, slightly dehydrated, normal appetite

26.a. What would you do first?

- o Administer an antibiotic. Which one? (Open question)
- o NSAIDS/fluids
- o Call the vet
- o Other

26.b. If you would not administer an antibiotic, what is the reason? (Tick all that apply).

- o It's not worth treating calves
- o The disease is not severe enough
- o Just one calf is affected
- o I want to use antibiotics responsibly
- o I don't usually use antibiotics for calf scour
- o It is not advised in my written protocols

26.c. What would you do to limit the spread to other calves? (Tick all that apply).

- o Nothing
- o Isolate the sick calf
- o I use specific tools/equipment for the sick animal
- o Feed the calf last
- o Do a prophylactic treatment to other calves
- o Other

27. Scenario 3: Cow: 10 days post-partum, smelly uterine discharge, temperature 39.5 °C

27.a. What would you do first?

- o Administer an antibiotic. Which one? (Open question)
- o NSAIDS/fluids
- o Call the vet
- o Monitor the cow
- o Other

27.b. If you treat the cows with an antibiotic, why would you choose it? (Tick all that apply).

- o I Follow my written treatment protocol
- o I do what the vet previously advised to me
- o Because it is cheap
- o Because I am familiar with this drug
- o Other

27.c. If you treat the cows with antibiotic, would you use the milk to feed the calves?

- o Yes
- o No
- o Only to some calves

28. Scenario 4: Six calves aged 1–2 months: cough, nasal discharge, fever (temperature > 39.5 °C)

28.a. What would you do first?

- o Administer an antibiotic. Which one? (Open question)
- o NSAIDS
- o Call the vet
- o Monitor
- o Other

28.b.If you treat the calves with an antibiotic, how do you know which calves have been treated? (Tick all that apply).

- o I do not record
- o Treatment book
- o Mark the calves
- o Computer
- o Other

28.c. If you treat the calves with an antibiotic, how long do you treat the calves for?

- o I follow my written protocols
- o I follow previous vet advice
- o I follow the instructions on the drug leaflet
- o Until the calves look well
- o Other

29. Diarrhoea in 20% of young calves (1–3 weeks old) over the last month, and a few of them died

29.a. What do you think is the most efficient action to take in order to prevent the other animals from getting infected?

- o Vaccinate cows
- o Take a faecal sample to identify the infectious agent
- o Do a prophylactic treatment
- o Other

29.b. Which other action would you take to reduce the spread of the infection on farm? (Tick all that apply).

- o Nothing
- o Cleaning and disinfecting the pens
- o Ensure colostrum intake/quality
- o Feeding sick animals at the end
- o Isolate sick animals
- o Other

30. Milking cow: sudden lameness in one hind limb

30.a. What would you do first?

- o Administer an antibiotic. Which one? (Open question)
- o Call the vet
- o NSAIDS
- o Wait for the foot trimmer
- o Examine the foot

30.b. If you choose to treat the cow with an antibiotic, how long would you treat the animal for?

o Until improvement of the lameness
o What worked in my experience
o What is recommended in my protocols
o Other

31. Milking cow: sudden milk drop and fever (temperature = 39.9 °C)

31.a. What do you do first?

o I administer an antibiotic. Which one? (Open question)
o I take a milk sample
o I call the vet
o NSAIDS/fluids
o Monitor
o Other

32. It is important to reduce antibiotic usage on UK dairy farms

o Strongly agree
o Agree
o Neither agree nor disagree
o Disagree
o Strongly disagree

33. Nowadays, there is too much reliance on antibiotic usage on dairy farms in the UK

○ Strongly agree

o Agree
o Neither agree nor disagree
o Disagree
o Strongly disagree

34. Decreasing antibiotic usage in dairy farms could help reducing antibiotic resistance in livestock

○ Strongly agree

o Agree
o Neither agree nor disagree
o Disagree
o Strongly disagree

35. Decreasing antibiotic usage in dairy farms could help reducing antibiotic resistance in humans

o Strongly agree
o Agree
o Neither agree nor disagree
o Disagree
o Strongly disagree

36. Some antibiotics work less effectively than in the past

o Strongly agree
o Agree
o Neither agree nor disagree
o Disagree
o Strongly disagree

37. Farmers require more training on antibiotic usage

o Strongly agree
o Agree
o Neither agree nor disagree
o Disagree
o Strongly disagree

38. Farm biosecurity and vaccination can reduce antibiotic usage

o Strongly agree
o Agree
o Neither agree nor disagree
o Disagree
o Strongly disagree

39. It is important to have protocols for antibiotic usage on farm

o Strongly agree
o Agree
o Neither agree nor disagree
o Disagree
o Strongly disagree

40. It is important to keep treatment records on farm and review antibiotic usage regularly

o Strongly agree
o Agree
o Neither agree nor disagree
o Disagree
o Strongly disagree

41. It is important to always respect the prescribed duration course of antibiotic

o Strongly agree
o Agree
o Neither agree nor disagree
o Disagree
o Strongly disagree

42. It is important to have hospital pens to isolate sick animals and avoid the spread of the diseases

o Strongly agree
o Agree
o Neither agree nor disagree
o Disagree
o Strongly disagree

43. It is important to always respect the withdrawal period of treated animals before slaughter or including the milk in the bulk milk tank

o Strongly agree
o Agree
o Neither agree nor disagree
o Disagree
o Strongly disagree

44. I am worried about antibiotic resistance on UK dairy farm

o Strongly agree
o Agree
o Neither agree nor disagree
o Disagree
o Strongly disagree

45. What is your age?

o 18–35
o 36–50
o More than 51
o Prefer not to say

46. What is your sex?

o Male
o Female
o Prefer not to say

47. How many years of experience (post-school age) in dairy farming do you have?

o Less than 5
o 6–20
o 21–40
o More than 41

48. What is your highest level of education?

o High school
o Agricultural college

o University
o Other

49. Is your dairy farm:

o Conventional
o Organic

50. Please provide an approximate number of dairy animals on your farm:

o Milking/dry cows
o Replacement heifers (weaned)
o Calves unweaned (male and female)
o Dairy bulls
o Other

51. Do you have any disease-free control accreditation? (Thick all that apply)

○ No

o BVD
o Johnes
o Lepto
o IBR
o Other

52. Have you bought new animals on to the farm over the last year?

o Yes
o No

53. Do you have other species/livestock types on farm?

o No
o Sheep
o Beef
o Other

54. What is your role in the enterprise?

o Owner
o Dairy manager
o Other

55. Please give an approximate value for each of the following questions.

o What is the average milk production par cow (litres)?
o What is the total milk production on the farm par year (litres)?
o What is the geometric average somatic cell count (cells/ml)?

56. Who is your milk buyer? (Optional question)

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