Borelli, Elena (2024) *Knowledge, behaviour and attitudes of Scottish dairy farmers toward antimicrobial usage and resistance.* MVM(R) thesis.

http://theses.gla.ac.uk/84270/

Knowledge, behaviour and attitudes of Scottish dairy farmers toward antimicrobial usage and resistance

Elena Borelli, DVM

Submitted in fulfilment of the requirement for the

Degree of Master of Veterinary Medicine

Scottish Centre for Production Animal Health and Food Safety

School of Biodiversity, One health & Veterinary Medicine

University of Glasgow

July 2023

Abstract

Antimicrobial resistance (AMR) is considered one of the most relevant global health threats. Understanding how farmers use antimicrobials and their awareness and beliefs about AMR is essential to improve antimicrobial usage (AMU) at the farm level. A cross-sectional online survey was carried out to explore Scottish dairy farmers' knowledge about the meaning of AMR and antimicrobial activity, behaviour and practices related to farm AMU and attitudes towards AMR mitigation. The second aim of this research was to identify the factors affecting the attitude, knowledge and behaviour of dairy producers regarding AMR and prudent AMU. An online survey was disseminated via multiple ways (e.g., social media; farming press). The target population was all Scottish dairy farmers (n = 832). Participation was voluntary and answers were obtained from 61 respondents (7.3% of the target population). Regression analyses were performed to identify predictors for farmers' level of knowledge about antimicrobials and AMR, AMU behaviour and attitudes towards AMR mitigation. Knowledge of AMR and antimicrobials was variable among participants. Greater knowledge was associated with holding a university degree (OR=28.28, $P<0.001$), working with mixed livestock (OR=4.82, $P<0.05$), and trusting only veterinarians' information about responsible AMU (OR=4.42, $P<0.05$). Indeed, veterinarians were overall described as the most important source of reliable information and the most influencing advisors on AMU. Many farmers (90%) self-reported a decreased AMU over recent years. In the survey disease scenarios, greater AMU was associated with younger age (OR=0.18, $P<0.05$) and working in large herds (OR=0.12, $P<0.01$). Despite the majority (89%) agreeing on the importance of reducing AMU on dairy farms, only 52% acknowledged that AMU on UK dairy farms is currently too high. 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 indicate that dairy farmers are aware of AMR and have recently reduced their farm AMU. However, more work is needed to improve their attitudes and responsibility to fight AMR. Many social, demographic, and economic factors influencing farmers' practices and intentions were identified in this study. Advisors should consider these factors when implementing behavioural change programs on farms.

Table of contents

Table of contents

List of tables

List of figures

Acknowledgement

Firstly, I would like to thank my supervisors Emily Hotchkiss and Kathryn Ellis for the for their great support, guidance and encouragement during this project and Residency.

I would like to acknowledge Niccole Pamphilis who gave me great inputs for the data analysis.

Special thanks to all farmers who collaborated to this project, all the people who helped in the dissemination of the survey and all colleagues of the Scottish Centre for Production Animal Health & Food Safety.

Finally, thanks to Lidl for funding this project.

Author's Declaration

I declare that this dissertation is the result of my work, except where explicit reference is made to other people's contributions. It has not been submitted for any other degree at the University of Glasgow or other institution.

Name: Elena Borelli

Chapter 1 – General Introduction

1.1. Scottish dairy farming

Dairy farming in Scotland has a long history and plays a significant role in the country's agricultural sector. Farms vary in size and geographical distribution, with most of the herds being concentrated in the southwest of the country. The number of dairy farms is approximately 830 (Farm Advisory Service, 2022). Scotland produces a substantial amount of milk, contributing to the overall dairy supply chain in the United Kingdom (UK). In 2021, the annual milk production exceeded 1.5 billion litres, with an average milk price of 28.6 pence per litre. Milk from Scottish dairy farms is processed by various dairy companies and cooperatives throughout the country producing a wide range of products such as milk, cheese, butter, yoghurt, and ice cream. Dairy farming in Scotland shares many similarities with the rest of the UK regions due to the common regulatory framework and market dynamics. However, the average herd size is slightly larger in Scotland (190 cows in Scotland; 150 cows in England and Wales; 125 cows in Northern Ireland). Scottish dairy farms exhibit a remarkable variety, ranging from extensively grazed low yielding cows, producing approximately 5,000 Litres of milk per lactation, to high input-high output herds housed all year round and producing over 12,000 litres per lactation. While the majority of herds calve all year round, a small percentage follows either a spring block, autumn block, or a combination of both calving patterns (Uberoi, 2021). Over three quarters of dairy herds are located across the south western sub-regions of Dumfries & Galloway, Ayrshire, and the Clyde Valley (Figure 1) (Scottish Government, 2016).

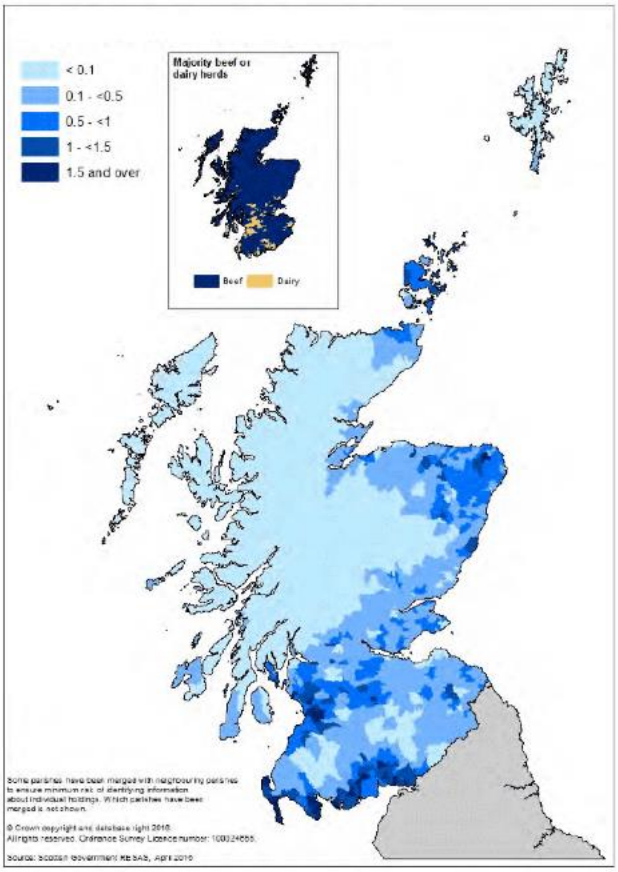

Figure 1- Cattle per hectare in Scotland (2015)

The economic situation of dairy farms in the UK is influenced by various factors, including milk prices, production costs, government policies, and market demand. Due to the decline in milk prices since 2014, dairy farming has faced several challenges in recent years and some farmers have struggled to maintain profitability (Downing, 2016). Dairy producers often face pressure to reduce costs and increase productivity to remain competitive. Intensifying farming practices, such as increasing herd size, using more efficient milking technologies, and optimizing feed management are some ways in which producers try to improve efficiency and reduce costs. However, intensification can have negative implications for animal welfare and environmental sustainability, such as increased use of antimicrobials.

Clinical mastitis, respiratory illness, lameness, and post-partum diseases are conditions that often necessitate the use of antimicrobials in dairy cows (Marshall & Levy, 2011). Dry cow treatment, wherein a long-acting intramammary antimicrobial infusion is administered to cows during the dry period to address existing and prevent the occurrence of new infections, represents another important reason for antimicrobial usage (AMU). In contrast to blanket dry cow treatment, in recent years selective dry cow therapy (SDCT) has been adopted as a practice to reduce AMU (McCubbin et al., 2022). With SDCT only cows having intramammary infections are targeted for antimicrobial administration, greatly enhancing the responsible AMU in the dairy industry.

Although infectious diseases are not completely avoidable in dairy farming, some practices such as respecting biosecurity rules, hygiene, sanitisation, and ensuring good overall animal health and environmental conditions can minimise the incidence and spread of disease and, as a consequence, the need for antimicrobials. Therefore, the first step to reduce antimicrobial resistance (AMR) risk in dairy is to improve the overall animal's health and husbandry conditions.

1.2. Farm antimicrobial usage estimation

Antimicrobials are used in food animals to treat disease (therapeutic use), prevent disease (prophylactic use), and, in some countries, enhance animal growth (subtherapeutic use) (Landers et al., 2012). Understanding how antimicrobials are used in livestock is crucial to advise antimicrobial stewardship policy; yet exact figures are hard to monitor and quantify. Three main methods can be used to obtain AMU data on a dairy farm: veterinary sales data, on-farm medicine records, and on-farm medicine waste bin audits. A recent study in the UK compared these three approaches and found that veterinary sales data were the most reliable, while farm medicine records showed the poorest accuracy (Rees et al., 2021). Farmers are legally required to register AMU; however, these data may often be incomplete. Despite presenting some limitations (e.g., drugs stocked and not used yet, sales from different practices, courses not completed), billing data are commonly used to monitor AMU in UK dairy farms. The main methods used to calculate AMU are mass-based methodologies (total mg and mg/kg) and dose-based methodologies (daily and course dose metrics) (Mills et al., 2018). The simplest method is the total mass of antimicrobials used (Total mg). Still, it has some crucial limitations, such as not considering the number of animals in the herd and the dose rate of each antimicrobial. Since new-generation antimicrobials and some Highest Priority Critically Important Antimicrobials (HP-CIAs) for human health have lower mg per dose than older drugs, it may lead to an underestimation of AMU in herds using CIAs (WHO, 2005). The second mass-based method is mg/kg, which divides the mass of the medicines used by the total weight of animals at risk of treatment; it overcomes the limitation of herd size but does not consider the different dose rates. Then, HP-CIAs should be measured and benchmarked separately from other classes of antimicrobials. Defined daily dose (DDD) metrics divide the total mg of medicine used by both total animal weight and the daily dose for that antimicrobial, accounting for different dose rates. Similarly, defined course dose (DCD) considers the daily dose and the course length. Hyde and colleagues (2017) calculated AMU in a sample of UK dairy farms using sales data. They found that injectable, oral, and footbath antimicrobials are the strongest drivers for AMU in mg/kg. In contrast, intramammary treatments drove mostly DDD and DCD due to their low dose in mg. Therefore, combining both methods may be the most appropriate approach to quantifying and monitoring AMU in dairy farms. Otherwise, some high AMU farms would not be detected with only one metric. The same study found that the highest 25% of antimicrobial users bought 52 % of the total mass of antimicrobials, suggesting the presence of some farms with very high AMU. In a similar study, Humphry et al. (2021) reported that the total antimicrobial consumption in Scottish dairy herds was 14.3 mg/kg. While the total estimated AMU was within the target set by RUMA for 2020, HP-CIA intramammary use was considerably over these targets (0.62 DCDvet/dairy cow vs. 0.166 DCDvet/dairy set by RUMA) (RUMA, 2017). Total AMU and HP-CIA usage were higher in dairy than beef herds, mainly due to macrolide usage.

1.3. Antimicrobial resistance mechanisms

Bacteria can have intrinsic or acquired resistance to antimicrobials. Intrinsic resistance is due to a structural or functional characteristic of a specific group of microorganisms, allowing them to be insensitive to a particular antimicrobial class. Commonly, it is provided by the lack of a target structure for specific antimicrobial agents (Reygaert, 2018).

Acquired resistance involves only some strains of a particular bacterial group and it is caused by an alteration of the bacterial genome. Acquired resistance can be secondary to a mutation of genes affecting the activity of the drug (endogenous resistance), to a horizontal acquisition of genetic material (exogenous resistance), or to a combination of both. In particular, horizontal gene transfer (HGT) is the most important method to acquire and spread resistance among the bacteria population and it can happen via the following routes (Guardabassi & Courvalin, 2019; Christaki et al., 2020):

- Transformation, when DNA molecules from other cells are assimilated directly from the extracellular space.

- Transposition, when a chromosomal fragment is spread between bacteria through a bacteriophage virus.

- Conjugation, when a direct connection between two bacteria is created through sexual pilus, and they exchange mobile genetic elements (MGEs) such as plasmids, integrons, and transposons. Conjugation is the most efficient method of gene transfer between bacteria.

There are four main mechanisms of resistance, and they are classified according to their biochemical mechanism: limiting uptake of a drug by altering the permeability of the bacterial membrane; modification or protection of a drug target by reducing the affinity for the antimicrobial molecule; inactivating the antimicrobial molecule, by producing enzymes rendering the drug unable to interact with its target; active extrusion of a drug, by using efflux pumps. The development of AMR by bacteria, viruses and fungi is a natural phenomenon. However, it is accelerated by excessive use and misuse of antimicrobials in human and animal populations (Reygaert, 2018).

1.4. Antimicrobial resistance on dairy farms

Food-producing animals can be the reservoir of resistant pathogenic strains of some zoonotic bacteria such as *Staphylococcus aureus*, *Escherichia coli*, *Listeria monocytogenes*, and *Salmonella* spp. (Sharma et al., 2018). *S. aureus* is one of the primary mastitis pathogens worldwide, and methicillin-resistant *S. aureus* (MRSA) infection poses a significant threat to public health due to the limited treatment with non-β-lactam antimicrobials and the potential zoonotic transmission through raw milk consumption (Schnitt and Tenhagen, 2020). Although the prevalence of AMR is lower than on pig farms and despite the role of cattle as a source of human infection remain unclear, MRSA prevalence in bulk tank milk has been reported to vary between 0% and 20% (Schnitt and Tenhagen, 2020). Despite studies suggesting that bacteria causing bovine udder infections are generally susceptible to the most common antimicrobials used (Jong et al., 2018), a recent meta-analysis reported an increasing trend of *S. aureus* resistance to all the antimicrobials evaluated (Mills et al., 2018). Saini et al. (2012) found a positive association between penicillin administration (injectable and intramammary) and penicillin resistance in *S. aureus* in Canadian dairy herds. In contrast, another study revealed a positive association between systemic AMU and the level of resistance of non-aureus staphylococci but no association with intramammary AMU (Nobrega et al., 2018). Antimicrobial susceptibility of pathogens causing subclinical mastitis was lower in herds using antimicrobial dry cow therapy than in herds not using AMU at dry off (organic herds) (McDougall et al., 2021). When monitoring AMR in dairy farms, using bacteria isolated from bulk tank milk samples may be a valuable method (Berge et al., 2007). In a study carried out in the UK, several practices have been associated with the antimicrobial susceptibility of bacteria isolated from the bulk tank, such as the presence of slurry storage, type of pre-milking teat disinfection, type of bedding and milking system (McLaughlin et al., 2022).

Reports show that the level of antimicrobial susceptibility in pathogens isolated from cattle remains relatively stable in the UK (especially for tetracycline, penicillin, aminoglycosides and sulphonamides) (UK-VARSS, 2021). The last UK-VARRS report described the *E. coli* resistance to non-HP-CIA had only limited annual fluctuations for most antimicrobials, but resistance to ampicillin has increased from 22% in 2017/2018 to 39-46% between 2019 and 2021; resistance to the beta-lactam ampicillin remains high (40.5%) and to tetracycline remains moderate (14.3%). *S. aureus* resistance to beta-lactam amoxicillin/clavulanate has increased from 7% to 12% over the monitoring period, while resistance to penicillin declined from 27.8% to 12%.

1.5. Antimicrobial resistance spread from livestock to humans

In countries where surveillance on AMU has been conducted for a long time (e.g., Denmark, Sweden, and the Netherlands), national surveillance reports showed that there is a link between the amount of antimicrobials administered in livestock and the level of AMR in pathogens causing animal infections (Bennani et al., 2020). In addition, several studies reported the association between antimicrobial use in the cattle production system and the occurrence of resistance in both commensal and opportunistic bacteria (Berge et al., 2006; Jarrige et al., 2020).

Despite there being no clear conclusion, AMU in animals is believed to be a risk for the emergence of AMR in the human bacterial population (Tang et al., 2017). Some studies have documented a genetic association between resistant bacteria isolated in humans and farm animals (Lee, 2003; Zhang et al., 2009). Antimicrobial resistance may spread between animals and humans by direct or indirect contact. Some occupational categories, such as veterinarians, farmers, and slaughterhouse workers, are more exposed to resistant organisms due to their close contact with infected animals. People can also indirectly be exposed to resistant bacteria through food, water, and animal waste application to farm fields (Marshall and Levy, 2011). Quantitatively, food is the most important transmission source of AMR between livestock and humans (FAO and VMD, 2022). In addition, the global trade of animal products has the potential risk to disseminate resistant bacteria across different countries (Founou et al., 2016). Associations between resistant genes of bacteria isolated in animal food products and humans have been reported, demonstrating the possibility of AMR passage through the food chain (Johnson et al., 2007). However, evidence proving this transmission route remains limited, perhaps due to the hygiene procedures of meat processing which can be very effective at removing bacteria (FAO and VMD, 2022).

Besides the direct infection from an animal source (infected animal or contaminated food/water), AMR may spread from livestock to humans through the diffusion of resistance genes from animal to human pathogens (HGT). In this regard, not only pathogenic bacteria must be considered as a threat to AMR. Indeed, commensal bacteria constantly exchange genetic material with other bacteria, and they may represent an important reservoir of resistant genes (the “resistome”) (Marshall and Levy, 2011).

Antimicrobial residues are another important factor driving the emergence of AMR by exerting selection pressure on bacteria. It is estimated that 75% to 90% of antimicrobials used in food animals are excreted largely unmetabolized and then discharged in the environment, such as in water, manure, and soils (Marshall and Levy, 2011). Furthermore, as environmental antimicrobial residues are not controlled as are other hazardous substances, their concentrations are likely to be underestimated (FAO and VMD, 2022). In addition to being a risk for AMR, antimicrobial residues in the environment can reduce soil bacteria which are important for the carbonate and nitrogen cycle (Wepking et al., 2019), and they also reduce methanogenic bacteria in biogas production from manure (Wolak et al., 2022).

1.6. Impact of antimicrobial usage in livestock on public health

In recent decades, the demand for animal protein for human consumption has increased dramatically. In low- and middle-income countries, the intensification of farming systems has led to a massive, rapid increase in AMU. Van Boeckel et al. (2019) estimated that between 2010 and 2030, the global use of antimicrobials in livestock will increase by 67% and, in some countries (e.g., Brazil, Russia, India, and China), it will increase by 99%. There is growing concern about the threat that AMR might pose to public health, resulting in human antimicrobial-resistant infections. Despite scientific evidence showing that transmission of antimicrobial-resistant bacteria between animals and humans is possible, there is a lack of conclusive and robust data demonstrating the amplitude of its impact on the overall burden of AMR (Founou et al., 2016). In a recent systematic review, Tang and colleagues (2017) reported that restricting AMU in livestock decreased antimicrobial-resistant bacteria in animals by about 15%. The evidence of the impact on public health was less and limited to people working in close contact with food production animals. However, some studies described a 24% absolute reduction in the prevalence of antimicrobial-resistant bacteria in humans with the intervention of reduced AMU in livestock (Tang et al., 2017). A mathematical model study found that lowering AMU in food-producing animals had little impact on the level of AMR in humans, whereas limiting the transmission of resistant bacteria from livestock to humans may be more beneficial (van Bunnik and Woolhouse, 2017). Despite there being no clear conclusions regarding the link between AMU and AMR in animals and humans, an integrated and multisectoral One Health approach is essential for controlling the burden of resistant bacteria. This involves the collaboration of various disciplines and representatives from different fields (environmental, human, and animal health) for a better understanding and management of AMR (FAO and VMD, 2022).

1.7. Guidelines on antimicrobial usage on UK dairy farms

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, and several guidelines about prudent AMU in veterinary medicine have been proposed over the last decades.

In 2005, the World Health Organisation established the first list of Critically Important Antimicrobials (CIA) based on two main criteria: "sole, or one of the limited available therapies, to treat serious human infections" and "used to treat infections caused by an agent that can be transmitted by non-human sources or with resistant genes from non-human sources" (WHO, 2005). Antimicrobial classes meeting both criteria are termed CIAs. The list has been reassessed several times. In the last and 6th revision of 2018, CIAs have been further divided into High Priority CIAs and Highest Priority CIAs (HP-CIAs) based on three prioritization factors. HP-CIAs are quinolones, polymyxins, macrolides, cephalosporins (3rd, 4th, and 5th generation), and glycopeptides (WHO, 2018) . The European Medicine Agency has also categorised the antimicrobials used in animals to protect the public and animal health (EMA, 2020). The classification comprises four categories: A ("Avoid"), B ("Restrict"), C ("Caution"), and D ("Prudence"). Category A includes antimicrobials not authorised in veterinary medicine by the EU. Recently, OIE classified antimicrobials into three categories, Veterinary Critically Important Antimicrobial Agents (VCIA), Veterinary Highly Important Antimicrobial Agents (VHIA), and Veterinary Important Antimicrobial Agents (VIA) (OIE, 2021). Along with the major international health organisations, the European Union (EU) and many European countries have developed regulations and directives on the prudent use of antimicrobials in veterinary medicine. The EU has banned antimicrobial use as growth promoters in livestock since the 1st of January 2006 (Regulation 1831/2003/EC). EU directives set requirements regarding raw milk microbiological, physical, and chemical hazards. Maximum Residue Limit (MRL) is an official EU standard and represents the maximum allowed concentration of residue in a food product from an animal treated with a veterinary medicine.

In 2011, the European Commission launched a 5-year action plan, recommending 12 actions to tackle AMR, such as responsible usage of antimicrobials, good hygiene practices, farm management, and disease surveillance (European Commission, 2011). In the UK, the Review on Antimicrobial Resistance published in 2016 proposed ten recommendations to combat the spread of AMR, addressing some important aspects such as infectious disease prevention and animal control (O'Neill J, 2016). Recently, the UK government issued the last 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 (Department of Health, 2019). Responsible AMU in food-producing animals in the UK is mainly industry-led. The government monitors AMU through medicine sales data, produces action plans to tackle AMR, and creates targets, whereas the industry is responsible for designing and implementing livestock sector policies (Begemann et al., 2020). This is made possible through compliance with retailer and supermarket standards and voluntary farm assurance schemes. For instance, the Red Tractor Scheme requires an annual veterinary review of AMU, the use of HP-CIAs as a last resort and under veterinary direction, and staff training for antimicrobial administration (Red Tractor Assurances, 2021). Some dairy retailer groups may have more stringent guidelines AMU in farmed livestock. For instance, some milk buyers, such as Organic Milk Suppliers Co-operative Limited (OMSCO), guarantee antimicrobial-free milk to consumers (Alliance to Save Our Antibiotics, 2021). Various detailed treatment guidelines for veterinarians and farmers are available in the UK. The Responsible Use of Medicines in Agriculture Alliance (RUMA) has formulated recommendations for farmers and veterinarians regarding prudent AMU in various animal species (RUMA, 2015). In addition, the British Veterinary Association (BVA) has published a 7-point antimicrobial plan poster, illustrating the critical action for responsible AMU (BVA, 2019).

As a result of the initiatives and the awareness-raising actions proposed by the government and international organisations, antimicrobial sales in livestock seemed to decrease over recent years. The last UK One Health Report described an average reduction of 35 % of the total tonnes of antimicrobials sold for animals between 2013 and 2017 (VMD, 2019). When considering only HP-CIAs, the AMU reduction was approximately 51 %. The Veterinary Medicine Directorate (VDM) produces an annual report on AMU using sales data: the UK Veterinary Antimicrobial Resistance and Sales Surveillance (UK-VARSS). The most recent version reported a reduction of 68 % in cattle injectable HP-CIAs between 2016 and 2020. In addition, there was a decrease of 78 % in intramammary HP-CIAs and

38 % and 34 % in lactating cow and dry cow therapy sales, respectively (UK-VARSS, 2021). In 2020, RUMA published the second set of targets which established a 15% fall of mg/kg of AMU in cattle and sheep by 2024 (RUMA, 2020).

1.8. Dairy farmers' knowledge of antimicrobials and AMR

Antimicrobial usage and the potential spread of AMR on dairy farms are largely affected by farmers' behaviour which, for its part, depends on cultural, social, and economic factors. In the UK, antimicrobials are a prescription-only medicine and must be recommended by a veterinary surgeon after a clinical assessment of the animal (The Veterinary Medicine Regulations No. 2033, 2013). However, if the veterinarian is actively controlling the farm and is aware of the animal's health status, farmers can gather, store, and administer antimicrobials without the practitioner being present (Loeb, 2021). Only monitoring AMU alone gives little evidence about farmers' beliefs and intentions. Therefore, much research is focusing on what influences farmers' behaviour and attitudes toward AMR to identify high-risk practices and design antimicrobial stewardship programs. Yet, there are still gaps in the current understanding of drivers and barriers to responsible AMU.

Farmer knowledge about antimicrobials and AMR varies considerably between studies and countries. Ozturk et al. (2019) reported a lack of knowledge and awareness of AMR among dairy farmers in Turkey. Some authors found that most producers thought AMR was a synonym for unsuccessful treatment (Schwendner et al., 2020) and were unfamiliar with the meaning of critical antimicrobials (Poizat et al., 2017). In England and Wales, only two-thirds were aware of the inappropriate usage of HP-CIAs as a first-choice antimicrobial (Jones et al., 2015), and only 55% provided an accurate description of AMR (Higham et al., 2018). Perceived knowledge was also poor in some studies, with some farmers admitting a lack of ability to properly use antimicrobials (Jones et al., 2015; Schwendner et al., 2020). On the other hand, farmers' knowledge of antimicrobials and AMR was higher in dairy compared to other livestock farming in the Netherlands (Kramer et al., 2017), and 72% of Washington dairy farmers were aware of the meaning of AMR (Raymond et al., 2006). Generally, researchers reported that knowledge and awareness were higher in high-income countries (Farrell et al., 2021). In contrast, in some developing countries, dairy farmers reported using antimicrobials as a preventive measure and treatment of non-bacterial diseases (Dankar et al., 2022). Despite most of the studies reporting low to moderate awareness of dairy farmers about AMR and AMU, these findings likely depend on the country's support and resources for producers, agricultural regulations that farmers need to be aware of, and dairy industries' initiatives and standards. The Scottish dairy farmers' knowledge of AMR and antimicrobials remain a knowledge gap.

1.9. Dairy farmers' antimicrobial usage behaviour

Several authors have explored farmers' behaviour around AMU. Recent surveys revealed that mastitis was the leading driver for AMU (Jones et al., 2015; Higham et al., 2018), and that penicillin was the most used antimicrobial (Higham et al., 2018; Falkenberg et al., 2019). Implementation of SDCT varied among studies and countries. In the UK, Brunton et al. (2012) found that 85% of farmers were treating all cows with antimicrobials at dry-off (blanket treatment), and a more recent survey reported that 96% of farmers were using antimicrobial dry cow treatment without specifying in which proportion of cows (Fujiwara et al., 2018). Other authors found that 58% and 77% of the farmers were implementing blanket dry-cow therapy in French and US dairy farms, respectively (Kayitsinga et al., 2017; Poizat et al., 2017), while in the Netherlands, 75% were using SDCT (Scherpenzeel et al., 2016). In the Netherlands, restrictions on AMU in livestock have been established since 2008 and this likely contributed to a greater awareness of AMR among Dutch dairy farmers (Tijs et al., 2022). Respiratory infections and lameness represent other important reasons for AMU on dairy farms (Raymond et al., 2006; Higham et al., 2018). Although international guidelines discourage the usage of HP-CIA usage, Brunton et al. (2012) found that cefquinome was the active ingredient in the second most frequently used intramammary tubes to treat mastitis, and Poizat et al. (2017) reported that 42% of French farmers were regularly using CIAs.

Farmers' decision-making around antimicrobials is influenced by several factors, with animal welfare and veterinarian recommendations being indicated as the most important (Jones et al., 2015; Swinkels et al., 2015; Golding et al., 2019; Schwendner et al., 2020;). Other aspects influencing decision-making were the withdrawal period (Ekakoro et al., 2019) and financial cost (Jones et al., 2015). Some recent studies investigated the uptake of best practices to reduce the risk of AMR, such as using culture and sensitivity tests, implementing treatment protocols, and discarding waste milk. Microbiological cultures of samples collected from affected animals (e.g., milk, faeces) are practical tools to identify pathogens and target antimicrobial therapy. Studies have reported that this practice is relatively widespread, being implemented by 60% to 70% of German and US farmers for the diagnosis of mastitis pathogens (Kayitsinga et al., 2017; Falkenberg et al., 2019), and more than 60% of Swiss producers always take milk sample before treating cows with antimicrobials (Schwendner et al., 2020). However, several studies identified limitations for the uptake of diagnostic tests usages, such as cost, sampling difficulties, time, and variable results (Skjølstrup et al., 2021).

Improved diagnostic specificity and more judicious AMU can be achieved through standard operating procedures on farms, such as AMU treatment protocols. The presence of treatment protocols was met rarely in Washington, German, and Swiss dairy farms (Falkenberg et al., 2019; Raymond et al., 2006; Schwendner et al., 2020), while other studies in North America found that approximately 40% of dairy producers were employing this tool for therapy decision-making (Habing et al., 2016; Uyama et al., 2022). However, the uptake of treatment protocols has never been investigated in Sottish dairy farms.

"Waste milk" is milk unfit for human consumption and includes milk from cows treated with antimicrobials or non-antimicrobial medicines that may leave residues, or milk from cows with mastitis. Studies have highlighted the potential risk of feeding milk containing antimicrobial residues in selecting resistant gut bacteria in calves (Jarrige et al., 2020; Firth et al., 2021). Brunton et al. (2012) found that 83% of farmers feed their calves waste milk. However, a more recent study reported that this practice occurred in less than half of the respondents' farms in the UK (Higham et al., 2018). It is likely the increased awareness of AMR and the risk associated with feeding waste milk to calves (e.g., the spread of pathogens such as *Mycobacterium avium* subspecies *paratuberculosis, Mycoplasma bovis, Salmonella* spp.) has reduced this practice among dairy producers in recent years. However, no recent data are available on the prevalence of producers feeding waste milk to calves in Scotland.

1.10. Dairy farmers' attitudes towards AMR

Understanding farmers' attitudes toward AMR is essential to implement specific strategies and achieving responsible AMU. Studies have shown that positive attitudes towards dry cow therapy and decreased AMU were related to whether farmers would implement SDCT (Scherpenzeel et al., 2016) and reduce AMU (Jones et al., 2015). Overall, studies reported a good level of awareness of the risk associated with irresponsible AMU, and many producers were conscious that this could contribute to the emergence of AMR in animals (Raymond et al., 2006; Jones et al., 2015; Golding et al., 2019; Schwendner et al., 2020). UK dairy farmers showed a positive attitude and a sense of ownership for improving AMU (Golding et al., 2019). Studies in Switzerland and Denmark reported that producers felt responsible for ensuring a safe product for consumers (Gerber et al., 2020) and that they recognised the importance of keeping records of AMU on the farm so that milk should be free from antimicrobial residues (Skjølstrup et al., 2021).

Despite the farmers being aware of AMR and its consequences on the dairy industry, they did not perceive AMR as a current threat or something they have encountered on their farms (Golding et al., 2019). Indeed, limited response to treatment was mainly attributed to other cow and pathogen factors, rather than resistance (Helliwell et al., 2019). AMR was considered distant from their local reality, as something which other countries or other farming systems should be concerned about. Producers feared more potential future legislation limiting their medicine usage (Golding et al., 2019).

Considerable evidence shows that farmers are more sceptical about the link between AMU in animals and AMR in humans (Jones et al., 2015; Ekakoro et al., 2019), especially among conventional farmers (Habing et al., 2016). UK and Danish farmers showed a defensive attitude, believing that they were unfairly blamed for contributing to a significant societal problem for which other countries or human physicians are more responsible. Also, they believed that other livestock industries impair their actions to reduce AMR with higher levels of medicine usage (e.g., swine) (Golding et al., 2019; Skjølstrup et al., 2021). This "other-blaming" behaviour and renunciation of responsibility can be a significant barrier to reducing AMU (Skjølstrup et al., 2021). Producers highlighted the importance of a global joint effort between all farm sectors, veterinarians, and human doctors to reduce AMR's public health consequences (Golding et al., 2019). In a recent study, dairy farmers perceived that consumers and politicians do not appreciate their effort to take care of animals and, at the same time, guarantee a safe product (Fischer et al., 2019). Producers were concerned about consumers' lack of knowledge and misconception of welfare and AMU, which could tighten regulations for medicine usage, and threaten their ability to treat sick animals effectively (Swinkels et al., 2015). Indeed, a US public survey reported that more than 90% of the respondents worried about the impact of AMU on dairy farms on human health (Wemette et al., 2021). Dairy farmers felt constrained by the system that requires cheap milk, which is linked to intensification, poor management, and increased AMU (Golding et al., 2019). Yet, research on an English dairy farm suggests that high levels of AMU are not necessary to maintain an intensive production system (Helliwell et al., 2019). In addition, Kuhnen et al. (2021) investigated the level of resistance of mastitis pathogens in different dairy husbandry systems, and they found that more intensive production was not associated with higher AMR, suggesting that other environmental factors may be more involved.

Negative attitudes towards regulations were seen more in dairy than other farming stakeholders, possibly due to the recent rules and more societal criticism (Kramer et al., 2017). Perceived ability to reduce AMU varied a lot between farmers. Some indicated that reducing medicine usage was feasible on their farm (Jones et al., 2015). Others believed that antimicrobials are only used when there are no alternatives and admitted that changing behaviour would be problematic (Fischer et al., 2019; Golding et al., 2019); these findings reveal a discrepancy between farmers' behaviour and what the dairy industry requires them to do. Dairy farmers have reported several barriers to responsible AMU. First, financial constraints, such as a change in farm structures and facilities (Wemette et al., 2021) and the cost of veterinary consultation and diagnostic tests (Fischer et al., 2019; Friedman et al., 2007; Golding et al., 2019). Farmers' general economic situation has been regarded as an essential limitation to changing AMU (Skjølstrup et al., 2021). Time and labour constraints were also mentioned, such as no time to wait for the veterinarian or the results of a diagnostic test (Friedman et al., 2007; Golding et al., 2019). Farmers reported concerns about productivity with milk production that would decrease if reducing antimicrobials (Raymond et al., 2006), and they thought that animal welfare would be compromised. Dairy producers felt a moral responsibility to maintain animals' health and supply a safe product, which meant it would not be possible to reduce AMU (Jones et al., 2015; Scherpenzeel et al., 2016; Wemette et al., 2021). Guaranteeing animal welfare and health was crucial for them to maintain the status of "good farmer" and conform to the social norms (Fischer et al., 2019). It explained why farmers might extend antimicrobial treatment over the recommendations (Swinkels et al., 2015).

On the other hand, farmers are motivated to reduce AMU by many factors. Training, education, and support are some drivers frequently reported. Producers desired better knowledge about AMU and diagnostic methods and asked for support in making changes, such as training courses, workshops, reading resources, and industry-led initiatives (Higham et al., 2018; Golding et al., 2019; Ozturk et al., 2019). In particular, veterinarian guidance and mutual support were believed essential to prevent disease, improve general cattle health, and reduce drug usage without compromising animal welfare and productivity (Scherpenzeel et al., 2016; Golding et al., 2019). Economic rewards and better financial support from industry were also important motivators for reduced AMU. Farmers would need better financial returns or financial incentives from milk buyers, to reinvest in farm buildings and staff training (Higham et al., 2018; Golding et al., 2019). Indeed, Jones et al. (2015) found that those receiving a more significant income from sold milk were more likely to demonstrate a positive intention to reduce their medicine usage. Motivation to reduce AMU could also originate from peers' need to be considered "good farmers". Farmers reported the importance of external approval from consumers, advisors, and veterinarians in several studies (Jones et al., 2015; Scherpenzeel et al., 2016; Fischer et al., 2019; Gerber et al., 2020). Reduced treatment cost (cost of antimicrobial and loss of milk during withholding period), and the consequently increased profit, were also seen as drivers for decreasing AMU (Jones et al., 2015; Schwendner et al., 2020; Wemette et al., 2021).

1.11. Changing farmers' behaviour

Farmers' behaviour towards best practices is crucial to limit the emergence of AMR; however, poor on-farm adoption of recommendations is common and behavioural change is often challenging to achieve in practice. Traditionally, enhancement in farming practices has been achieved through the implementation of regulations, legislation, and penalties, such as penalties for high somatic cells count (SCC) or antimicrobial residues in milk (Bard et al., 2019). These approaches (top-down) can be effective and obtain a widespread and quick behavioural change (Skjølstrup et al., 2021). However, since farmers tend to have an individualistic approach, compulsive instruments are not always well implemented and accepted, and they may introduce unwanted behaviour, such as not recording the use of antimicrobials, purchasing medicine online or using more veterinary practices as a source of drugs (Skjølstrup et al., 2021). Other approaches used to motivate farmers might be incentives and financial support. However, farmers may implement changes only as long as the motivators are in place (Ritter et al., 2017).

The uptake of recommendations is generally influenced by farmers' demographic factors, experience, and economic background. Indeed, to obtain an effective behaviour change, it is important to understand the farm context (e.g., regulations, milk price) and producers' motivation, perceived ability, and farming worldview (Ritter et al., 2017). In a recent study, veterinarians reported knowing in advance whether a farmer would react as an advice-taker (positive) or advice-leaver (negative) based on their personality (Bard et al., 2019). For these reasons, tailored and farmer-specific interventions are far more effective than standardised solutions (Helliwell et al., 2019; Morgans et al., 2021).

Farmers need to be provided with a sense of ownership to reduce AMU, and they must be actively involved in finding solutions (Speksnijder and Wagenaar, 2018). In a recent review, Skjolstrup et al. (2021) described the importance of "self-efficacy" (trust in own ability) for changing farmers' behaviour. For instance, participatory farmer-led approaches have been proposed as an effective strategy to reduce AMR. This method involves group discussions during which suggestions are proposed directly by farmers (Morgans et al., 2021). Peers' recommendations are often deemed more practical and achievable than veterinarians' recommendations. In addition, farmers' discussion creates a shared understanding and promote active engagement, rather than a passive consumption of information (Bard et al., 2019; Skjølstrup et al., 2021). Regular meetings with veterinary and peer support and periodic review of medicine usage have been reported as practical tools to reduce AMU (Speksnijder and Wagenaar, 2018; Gerber et al., 2020; Morgans et al., 2021).

In the context of cattle diseases, veterinarians are often considered the most truthful source of information (Biesheuvel et al., 2021). Their frequent contact with farmers has been associated with positive outcomes, such as higher awareness of AMR (Higham et al., 2018). Ritter et al. (2019) found that Canadian dairy farmers are overall satisfied with veterinarian services and communication. Nevertheless, in a recent systematic review, Farrell et al. (2021) reported that dairy producers felt the relationship was not reciprocal and emphasised the importance of mutual trusting collaboration. Farmers want to feel that the practitioner understands their farm context (Bard et al., 2019). In addition, Speksnijder et al. (2018) found that AMU was seen from a different point of view, with farmers prioritising the prevention of animal suffering and veterinarians following their ethical obligation. On the other hand, veterinarians felt that farmers are reluctant to change their practices regarding AMU (Llanos-Soto et al., 2021). Thus, practitioners may avoid actions in line with antimicrobial stewardship to address clients' expectations rather than creating conflicts. In this regard, improving veterinary-farmer communication is essential to understand each other's perspectives better, establish a common goal, and work efficiently to reduce AMU. Indeed, Ritter et al. (2019) reported that farmers reporting higher satisfaction with veterinary services were more prepared to adopt veterinarian recommendations. Since veterinarians' opinion strongly influences farmers' behaviour, practitioners' education about antimicrobial stewardship is crucial. Some studies indicated that veterinarians might prescribe antimicrobials as a risk-avoiding strategy to prevent complications. Sometimes, they perceive their role as a service provider of fast and cheap solutions rather than a reliable advisor (Speksnijder and Wagenaar, 2018). Similarly, a recent international survey (Llanos-Soto et al., 2021) indicated that around half of dairy practitioners might overprescribe antimicrobials.

1.12. Aims of the study

Although there is extensive literature describing the awareness, attitudes and behaviour of farmers towards AMR, limited information is available about UK producers, and no previous studies have examined these aspects specifically in the Scottish dairy sectors. The different agricultural policies and milk retailers' requirements, herds' managements, and farmers' backgrounds in Scotland likely affect the perception and beliefs of farmers around this topic. In addition, research gaps exist regarding the factors driving the uptake of best practices and responsible AMU behaviour, and the awareness and attitudes of dairy farmers to reduce AMU and combat AMR.

Therefore, the first aim of this study was to investigate the awareness, attitudes and behaviour of Scottish dairy farmers related to AMR and AMU. In particular:

- Assessing farmers' understanding of antimicrobials and AMR
- Exploring the implementation of best practices (e.g., discarding waste milk; SDCT) and farmers' AMU behaviour through some clinical disease scenarios
- Identifying which factors and people most influence farmers' antimicrobial choice and usage
- Investigating how AMU has changed in recent years and the main limitations associated with its reduction.
- Examining the perceptions and attitudes of farmers towards AMR mitigation and towards the implementation of AMU responsible practices (e.g., respecting withdrawal period, isolating sick animals, having AMU treatment protocols on the farm)

The second aim of the study was to identify farmers' traits and herd-level factors influencing the AMR and AMU knowledge, behaviour and attitudes of Scottish dairy farmers.

Chapter 2 - Antimicrobial usage and resistance in Scottish dairy herds: A survey of farmers' knowledge, behaviours and attitudes

Published in "BMC Veterinary Research". Reference:

Borelli E, Ellis K, Tomlinson M, Hotchkiss E. Antimicrobial usage and resistance in Scottish dairy herds: a survey of farmers' knowledge, behaviours and attitudes. BMC Vet Res. 19(1):72. doi: 10.1186/s12917-023-03625-0.

2.1. Abstract

Antimicrobial resistance (AMR) poses a major threat to global health. Understanding how antimicrobials are used on dairy farms and stakeholder beliefs relating to their use is essential to ensure responsible antimicrobial usage (AMU) to tackle the emergence of AMR. This study explored Scottish dairy farmers' knowledge about the meaning of AMR and antimicrobial activity, behaviour and practices related to farm AMU and attitudes towards AMR mitigation. An online survey was designed based on the findings of two focus groups and was completed by 61 respondents (7.3% of the total population of Scottish dairy farmers). Knowledge of antimicrobials and AMR was variable, and almost half of the participants believed that antimicrobials could have anti-inflammatory or analgesic activity. Veterinarians' opinions and advice about AMU were ranked significantly more important than other social referents or advisors. The majority of farmers (90%) reported having implemented practices to reduce reliance on antimicrobials (e.g., selective dry cow therapy, AMU treatment protocols) and having reduced farm AMU over recent years. Feeding waste milk to calves is still widespread, being reported by up to 30% of respondents. The main factors described to hinder responsible farm AMU were limited facilities (e.g., lack of isolation pens for sick animals) and knowledge of appropriate AMU recommendations, followed by time and financial constraints. Most farmers (89%) agreed that it is important to reduce AMU on dairy farms, but fewer (52%) acknowledged that AMU on UK dairy farms is currently too high, suggesting a mismatch between their intention to reduce antimicrobials and AMU behaviour. These results indicate that dairy

farmers are aware of AMR, and their self-reported farm AMU has been reduced. However, some do not clearly comprehend the activity of antimicrobials and their correct usage. More work is needed to improve dairy farmers' knowledge of appropriate AMU and intentions to combat AMR. Farmers would benefit from more regular AMU discussions and advice from herd veterinarians, as they were described as highly trusted information resources. Training on how to reduce AMU should involve all farm staff administering antimicrobials and should be tailored to farm-specific barriers, such as limited facilities and workforce shortages.

2.2. Introduction

Antimicrobial resistance (AMR) has been declared one of the top ten public health threats facing humanity (WHO, 2021). Two major drivers for acquired AMR are excessive use and misuse of antimicrobials in humans and animals (Marshall and Levy, 2011). The emergence of resistant bacteria may lead to increased morbidity and mortality in cattle, resulting in compromised animal welfare and economic losses (Call et al., 2008). In addition, scientific evidence has indicated that antimicrobial usage (AMU) in animals may contribute to AMR in humans (Tang et al., 2017), and food-producing animals can be a reservoir of resistant pathogenic strains of some zoonotic bacteria such as *Staphylococcus aureus, Escherichia coli, Listeria monocytogenes, and Salmonella* spp. (Sharma et al., 2018). Based on the precautionary principle, it is necessary to address irresponsible AMU in food-producing animals to prevent potential adverse animal and public health consequences.

In dairy herds, antimicrobials are frequently used to treat infections in adult and young animals, with the control of udder infection representing the main reason for AMU (Krömker and Leimbach, 2017). In the UK, antimicrobials are a prescription-only medicine prescribed by a veterinary surgeon after a clinical assessment of the animal (The Veterinary Medicine Regulations No. 2033, 2013). However, farmers often store and administer antimicrobials without the guidance of a veterinarian. Farm AMU is usually estimated from veterinary practices' sales data or on-farm records (Hyde et al., 2017); however, monitoring AMU alone gives little evidence about farmers' beliefs and intentions to reduce AMU. Understanding how antimicrobials are used in livestock is crucial for the development of antimicrobial stewardship programmes. Therefore, significant literature exists regarding what influences farmers' behaviour and attitudes towards AMR, high-risk practices, and barriers and drivers for responsible AMU.

Along with the major international health organisations, many countries have developed regulations and directives on the prudent usage of antimicrobials in veterinary medicine. Recently, the UK government issued the most recent UK five-year national action plan, "Tackling antimicrobial resistance 2019-2024", which focuses on reducing the need for antimicrobials through good husbandry, disease prevention, and biosecurity (Courtenay et al., 2019). The Responsible Use of Medicines in Agriculture Alliance (RUMA) has formulated many guidelines for farmers and veterinarians regarding prudent AMU (RUMA, 2015). In addition, many dairy product purchasing companies are now requiring their supplier farms to demonstrate responsible AMU (Begemann et al., 2020). Yet, little is known about the uptake of the guidelines and the implementation of best practice recommendations on farms.

Previous studies in the UK report that farmers are generally aware of the emergence of resistant bacteria and recognise their responsibility to reduce AMU; however, there are other priorities than AMR in their everyday decision-making (Golding et al., 2019). Dairy farmers often express concerns about the consequences of restricting AMU on productivity and animal welfare (Golding et al., 2019). Also, they indicated several barriers to AMU reduction at the farm level, such as economic challenges, lack of skills and inadequate knowledge of the guidelines (Jones et al., 2015, Higham et al., 2018, Golding et al., 2019).

To the authors' knowledge, no work to date has been carried out exploring stakeholder knowledge, behaviour, and attitudes relating to AMU and AMR in the Scottish dairy sector. Therefore, the objectives of this study were to investigate Scottish dairy farmers' knowledge of antimicrobials and the meaning of AMR, the uptake of best practices to fight AMR, whether farm AMU has changed, and how they foresee it changing in future years. In addition, we aimed to assess dairy farmers' attitudes towards AMR mitigation and the drivers, barriers, and facilitators to responsible farm AMU.

2.3. Materials and methods

Study population

A cross-sectional online survey was conducted in Scotland between the 26th of April and the 31st of August 2021. The survey URL was promoted in multiple ways (via the farming press, social media, veterinary practices, and milk buyers), and participation in the study was on a voluntary basis. The target population included all Scottish dairy farmers. Inclusion criteria were working on a Scottish dairy farm and being responsible for antimicrobial administration. Due to some specific dairy questions (e.g., milk production, somatic cell count), it would not have been possible for non-dairy farmers to complete the survey. According to the Scottish Dairy Cattle Association, there were 832 dairy farms in Scotland in 2021 (Farm Advisory Service, 2022). Participants were provided with a Participant Information and Consent Form at the start of the survey. Although the survey was anonymous and did not collect personal information, farmers could disclose their e-mail addresses once the survey was submitted to participate in a prize draw to win one of four £25 Lidl vouchers, which was included as an incentive to complete the survey. The email address was solely used for the purpose of the prize draw. Findings from a focus group and workshop were used in the development of the survey. This research gained ethical approval from the local ethics committee (the College of Medical, Veterinary and Life Sciences, University of Glasgow).

Focus group and workshop

As a result of the COVID-19 pandemic, the focus group and workshop were conducted remotely. The four authors attended and facilitated the discussion at both events. The focus group was held in August 2020 and included a convenience sample of dairy farmers personally known by the authors (n=5). A PowerPoint presentation was used as a visual aid displaying some images (e.g., milk samples) and specific questions which are listed in Appendix I. The workshop was part of an online agricultural event (Agriscot 2020) held in November 2020, during which the authors presented some questions (Appendix I) via multiple polls to online participants (approximately n=40). Only Scottish dairy farmers were encouraged to answer. The responses were displayed and used to elicit discussion, including via the chat function.

Some of the findings collected were used for the design of the survey. For instance, examples given by participants were used as options in the multiple-choice questions (e.g., best practices implemented on farms, barriers/drivers for AMU reduction).

Survey design

The survey was devised using the Online Surveys tool for which the University of Glasgow holds an institutional license (JISC survey) and was structured in four main sections. It consisted of multiple-choice, matrix, ordinal, and open-ended questions to explore farmers' knowledge, reported behaviours, and attitudes toward AMR. Antimicrobials discussed in the manuscript refer only to antibiotics.

Section One explored farmers' awareness and understanding of AMR, the importance of the opinion of some social referents (e.g., veterinarian, milk buyer, consumers, other farmers) regarding their AMU, and their contact with veterinarians.

Section Two included questions investigating farmers' AMU and implementation of practices to reduce reliance on antimicrobials. In addition, they were asked how their AMU has changed over the last few years and how they foresee it changing over the next five years. In this section, seven common dairy cattle disease scenarios (clinical mastitis, metritis, calf diarrhoea and pneumonia, lameness, drop in milk production) were described to assess the likelihood of farmers administering antimicrobials and following best practices (e.g., record keeping, waste milk disposal, duration of antimicrobial treatment, and biocontainment measures) (Table 1).

Table 1- Description of seven clinical disease scenarios typically encountered on dairy farms, included as part of a survey of Scottish dairy farmers.

Scenario	Description
1	Milking cow: signs of mild mastitis (milk modified, udder inflamed, no fever, no systemic symptoms)

2	1-week-old calf: diarrhoea, no fever, slightly dehydrated, normal appetite
3	Cow: 10 days post-partum, smelly uterine discharge, temperature 39.5 °C
4	Six calves aged 1-2 months: cough, nasal discharge, fever (temperature > 39.5 °C)
5	Diarrhoea in 20% of young calves (1-3 weeks old) over the last month and few of them died
6	Milking cow: sudden lameness in one hind limb
7	Milking cow: sudden milk drop and fever (temperature = 39.9 °C)

In Section Three, participants were asked to rate attitudinal statements on a five-point Likert scale (from strongly disagree to strongly agree). Statements were created based on the authors' experience and focus group/workshop findings, and explored farmers' concerns and opinions about AMR, the necessity to reduce AMU in livestock and its impact on public health, and the importance of some best practices on farms (e.g., record keeping, drug protocols, hospital pen).

Section Four gathered demographic and production information of the participants and the farm.

A pilot study was performed using a group of dairy farmers personally known by the authors (n=5) to test the survey duration and suitability of the questions to the target population. The final survey included 54 main questions, with 33 of these being multiple choice, 13 Likert scale, five matrix, two open-ended, and one ordinal. In some cases, a comment field was provided to enter free text. Some questions were followed by sub-questions depending on the answer selected (skip pattern). With the exclusion of the name of the milk buyer and the personal e-mail address, it was required to answer all questions to submit the survey. The survey is available in Appendix II.

Statistical analysis

Data were downloaded from the Online Surveys tool in an electronic Excel dataset format and were cleaned to remove potential missing or error data. Data analyses were performed using R Core Team (2020).

Demographic and herd production data of respondents were assessed to investigate whether the sample was representative of the target population with respect to herd size, somatic cell count (SCC), and milk yield (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.

Descriptive statistics

Descriptive statistics of responses (frequencies and proportions) were analysed for each question. Continuous variables (herd average SCC, milk yield, and the number of milking cows) were tested for normality with the Shapiro test and described with mean or median, minimum, and maximum. Responses to the open-ended knowledge question ("What does AMR mean to you in your own words?") were categorised into common themes based on the respondent's interpretation.

Visual representation and statistical test of Likert and matrix responses

Responses to matrix questions and attitudinal five-point Likert scale were represented with stacked bar charts. Differences between the ranking of the factors were compared with the Kruskal Wallis test, followed by pairwise comparisons with the Wilcoxon test and Benjamini and Hochberg correction. Attitude responses were also tested for internal reliability with the aid of Cronbach's alpha coefficient.

Univariable associations

Univariable associations between categorical variables of interest were tested with the Pearson chi-squared test or Fisher exact test, and significant associations were reported in the manuscript. With this aim, the four categories of RUMA guideline familiarity (Q.5 and Q.5.a) were combined into three levels: low (answers "never heard" and "not familiar at all"), medium (answer "somewhat familiar"), and high familiarity (answer "very familiar"). The level of agreement with the statement "I am worried about AMR on UK dairy farms" (Q.44) was categorised into three groups: disagree (answers "strongly disagree" and "disagree"), neutral (answer "neither disagree nor agree") and agree (answers "agree" and "strongly agree"). The frequency of veterinarian discussion about AMR (Q.9 and Q.9.a) was categorised into three levels: never (answer "never discussed"), once a year (answer "annually") and twice a year or more (answers "every six months", "monthly" and "at every visit"). The level of significance was set at $P < 0.05$.

2.4. Results

In total, 61 respondents completed the survey, accounting for 7.3% of the 2021 population of Scottish dairy farmers. All versions were answered completely, and none were excluded from the analysis.

Demographic data

Demographic data are summarised in Table 2. Most respondents were male (90%). The most frequent highest-level of education reported was agricultural college (52%), followed by university (33%) and high school (15%). Almost half of the farmers were between 36 and 50 years old and had between 21 and 40 years of experience in farming. Farm owners represented 72% of respondents, whilst the rest were employees (dairy managers). Most farms (93%) were conventional (not organic). Over half (52%) were breeding only dairy cows, while the rest included beef and/or sheep farming. Regarding infectious disease status, 10% of the herds did not have any disease-free accreditation, almost half (48%) reported only Bovine Viral Diarrhoea (BVD) free accreditation, while the remainder had other disease-free accreditation in addition to BVD. Median herd size (milking and dry cows) was 192 adult cows (range 46-1790); herd mean 305d milk production per cow was 8,999 Kg (range 5000-16000 Kg); herd mean SCC was 135,000 cells/ml (range 56,000-215,000 cells/ml). Sample herd size, milk production and average SCC were representative of the general population of Scottish dairy farms ($P > 0.05$, Two-sample Kolmogorov-Smirnov test).

Table 2 – Results of a survey of Scottish dairy farmers - farmer demographics and farm characteristics.

Q	Indicators	Categories	N	%
45	Age	18-35	13	21 (13/61)
		36-50	28	46 (28/61)
		>51	20	33 (20/61)

46	Sex	Male	55	90 (55/61)
		Female	6	10 (6/61)
47	Years in farming	<5	0	0 (0/61)
		6-20	20	33 (20/61)
		21-40	26	43 (26/61)
		>41	15	25 (15/61)
48	Education level	High school	9	15 (9/61)
		Agricultural college	32	52 (32/61)
		University	20	33 (20/61)
49	Farm system	Conventional	57	93 (57/61)
		Organic	4	7 (4/61)
51	Disease free accreditation	None	6	10 (6/61)
		Only BVD[a]	29	48 (29/61)
		BVD[a] plus other (IBR[b]/Leptospirosis)	26	42 (26/61)
52	Cattle bought last year	No	37	61 (37/61)
		Yes	24	39 (24/61)
53	Farm type	Only dairy	32	52 (32/61)
		Dairy and beef	9	15 (9/61)
		Dairy and sheep	10	16 (10/61)
		Dairy, sheep, and beef	10	16 (10/61)
54	Role	Owner	44	72 (44/61)
		Dairy manager	17	28 (17/61)

[a] Bovine viral diarrhoea
[b] Infectious bovine rhinotracheitis

Section One (Knowledge: Farmer awareness and understanding of AMR)

Farmer understanding of AMR (open-ended question) varied: around a third gave a correct interpretation referable to "bacteria develop resistance and do not respond to some antimicrobials", while the remaining indicated AMR as a "loss of efficacy of antimicrobials" (e.g., "antibiotics are not working anymore") or "resistance to the drug developed by animals" (e.g., "animals become immune to antibiotics") (Table 3). All farmers answered that antimicrobials are effective against bacteria, although 31% believed they could also be effective against viruses and 25% against parasites. Almost half of the respondents thought that antimicrobials have an anti-inflammatory and/or analgesic effect. The majority (92%) had discussed AMR with their veterinarians. This happened generally once a year for half of them, while the remaining reported a higher frequency (twice a year or more). Respondents showed good awareness of RUMA, with 90% having heard about the guidelines before. Of them, 71% and 22% reported being moderately familiar and very familiar with the recommendations. It was found that perceived knowledge of RUMA recommendations was significantly higher in owners than employees ($P < 0.05$, Pearson's chi-squared test).

Table 3- Results of a survey of Scottish dairy farmers - farmer awareness and understanding of antimicrobial resistance (AMR).

Q	Indicators	Categories	N	%
2	AMR definition (open question)	'Resistance to antibiotic developed by animals'	17	28 (17/61)
		'Loss of efficacy of antibiotics'	23	38 (23/61)
		'Resistance to antibiotic developed by pathogens'	21	34 (21/61)
3	Antibiotics are effective against	Bacteria	61	100 (61/61)
		Virus	19	31 (19/61)
		Parasite	15	25 (15/61)
4	Activity of antibiotic	Only anti-bacterial	32	52 (32/61)
		Anti-bacterial and anti-inflammatory and/or analgesic	29	48 (29/61)
5	Heard about RUMA[a] before	Yes	55	90 (55/61)
		No	6	10 (6/61)
5.a	Familiarity with RUMA[a]	Not familiar at all	4	7 (4/55)
		Somewhat familiar	39	71 (39/55)
		Very familiar	12	22 (12/55)
6	Frequency of routine visit in the last month	Never	9	15 (9/61)
		Once	21	34 (21/61)
		More than once	15	25 (15/61)
		Once every week/more	16	16 (16/61)
7	Required an emergency visit in the last month	Never	26	43 (26/61)
		Once	24	39 (24/61)
		More than once	6	10 (6/61)
		Once every week/more	5	8 (5/61)
9	Antibiotic resistance previously discussed with veterinarian	Yes	56	92 (56/61)
		No	5	8 (5/61)
9.a	Frequency of antibiotic resistance discussion with veterinarian	Annually	28	50 (28/56)
		Every six months	21	37 (21/56)
		Monthly	7	13 (7/56)
		At every visit	0	0 (0/56)
8	Veterinarian consultation before antibiotic usage	Never	1	2 (1/61)
		Sometimes	43	70 (43/61)
		Most of the time	11	18 (11/61)
		Always	6	10 (6/61)
16	Main reason for veterinarian consultation before antibiotic usage	Economic value of animal	27	45 (27/60)
		Previous treatment unsuccessful	17	28 (17/60)
		Animal welfare	15	25 (15/60)
		Several animals involved	1	2 (1/60)
17	Main reason for not consulting the veterinarian before antibiotic usage	I have enough experience	26	47 (26/55)
		Cost	17	31 (17/55)
		Delay in treating animal	12	22 (12/55)
		Additional work	0	0 (0/55)

[a] Responsible Use of Medicines in Agriculture Alliance

Farmers indicated which sources they consult for AMU guidance and to what extent they trust the information (Figure 2). Veterinarian information was ranked significantly more reliable than other sources (P < 0.001, Kruskal-Wallis), followed by web information. Milk buyer, farming articles, and other farmers' information were considered less trustworthy sources of information.

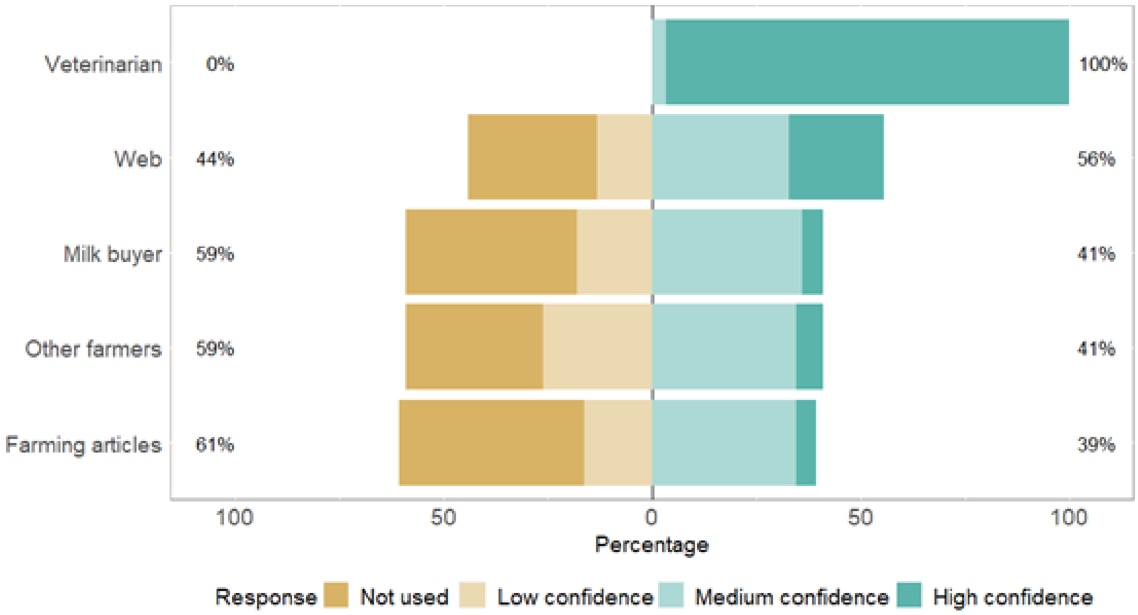

Figure 2- The confidence in different sources of information used by Scottish dairy farmers regarding responsible antimicrobial usage. The proportions of farmers ranking each source of information as not used/used with low confidence (scores 1 and 2) or used with medium confidence/used with high confidence (scores 3 and 4) are indicated.

Around two-thirds of farmers reported occasionally consulting their veterinarian before using antimicrobials, whilst the remainder asked for advice most of the time (18%) or always (10%). Only one farmer admitted to never seeking a veterinarian's opinion before AMU. High economic value of the animal represented the main reason for a veterinary consultation (27/60, 45%), followed by failure of previous treatment (17/60, 28%) and concerns over animal welfare (15/60, 25%). One farmer consulted veterinarians primarily when multiple animals are affected. Sufficient perceived personal experience was the main reason for not calling the veterinarian (26/55, 47%), followed by cost (17/55, 31%) and delay in treatment (12/55, 22%).

Farmers were questioned on the importance of the opinion of some social groups regarding their AMU (Figure 3). Their veterinarian's opinion was significantly more important than others' opinions (P < 0.001, Kruskal-Wallis). It was followed by milk buyers' and consumers' opinions, which were ranked significantly higher than family, colleagues, and other farmers' opinions (P < 0.001, Kruskal-Wallis).

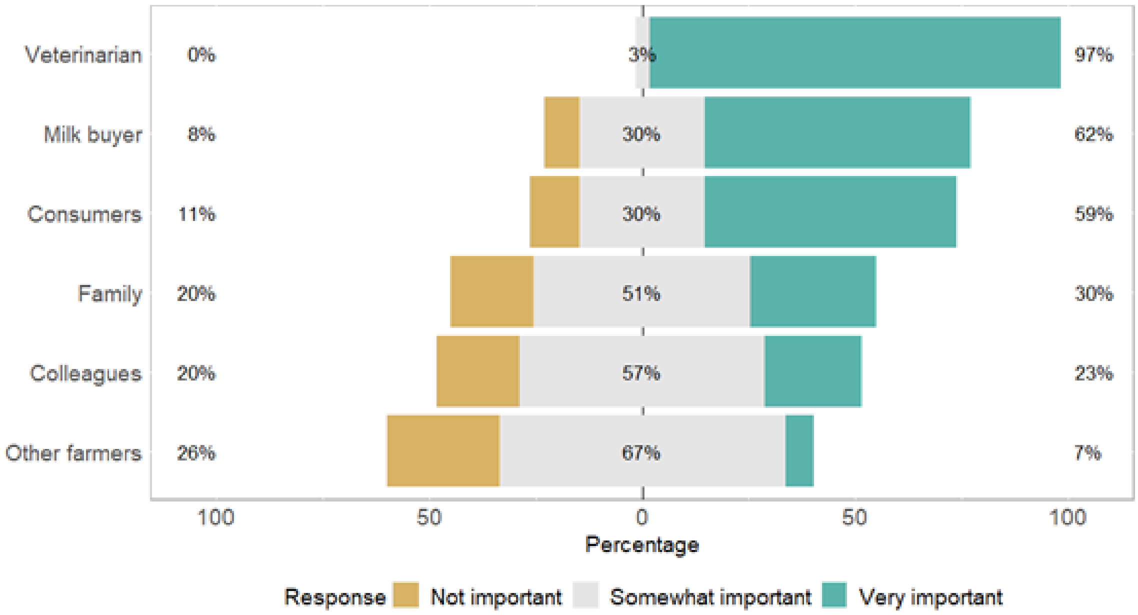

Figure 3 - The importance of the opinion of some social referents for Scottish dairy farmers regarding their antimicrobial usage. The proportions of farmers ranking the opinion of each social referent as not important (score 1), somewhat important (score 2) and very important (score 3) are indicated.

Section Two (Reported Behaviours: antimicrobial usage on farm)

Farmers indicated to which extent some factors influence their antimicrobial choice (Figure 4). Veterinary advice and previous usage experience were ranked as more important than other factors in medicine choice (P < 0.001, Kruskal-Wallis). The withdrawal period was more important than the cost (P < 0.001, Kruskal-Wallis).

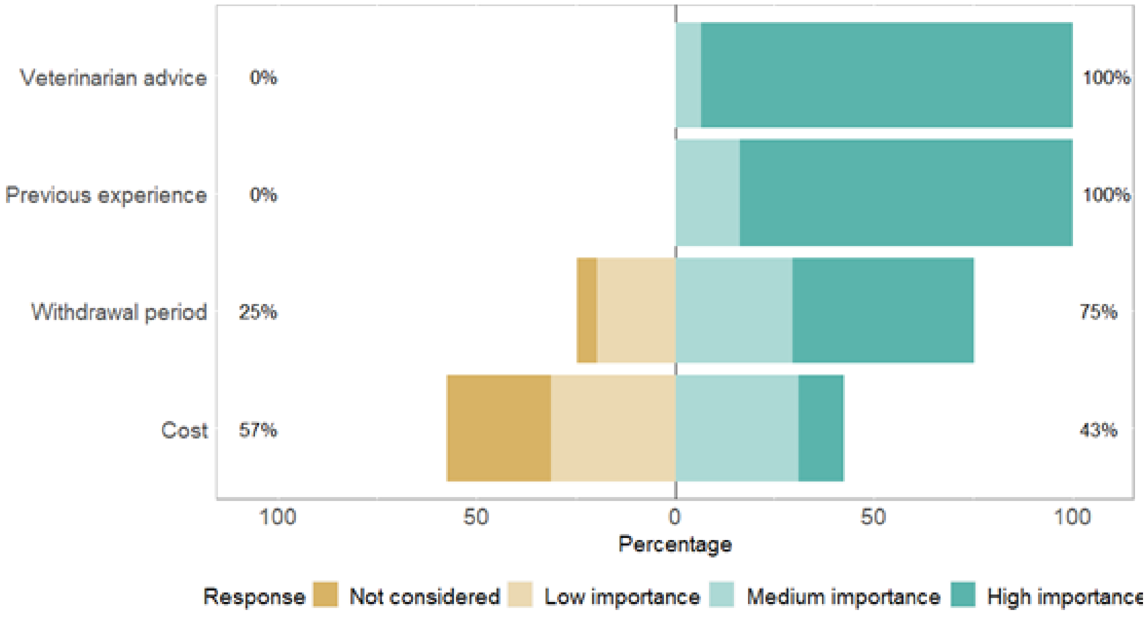

Figure 4 - The importance of some factors considered for antibiotic choice by Scottish dairy farmers. The proportions of farmers ranking each factor as not considered/considered with low importance (scores 1 and 2) or considered with medium importance/considered with high importance (scores 3 and 4) are indicated.

Table 4 summarises the results of farmers' AMU behaviour. Farmers ranked a list of common diseases from the most frequent (1st) to the least frequent (6th) reason for antimicrobial administration. Overall, udder health was ranked first by 80% of the farmers, with 59% indicating "mastitis" and 21% indicating "dry cow therapy" as the main drivers for AMU. Calf pneumonia was another important reason for AMU, ranked first by 15% of the farmers. Post-partum disease, calf diarrhoea, and lameness were less frequently reported as the primary cause of AMU. Penicillin was the antimicrobial most commonly used by 85% of farmers.

Most farmers (90%) reported having implemented practices to reduce farm AMU, and the same proportion reported having decreased their AMU in recent years. Half of the farmers thought limiting their AMU was difficult, with limited facilities and lack of knowledge being the main barriers (Figure 5). Regarding future intention, 87% of farmers planned to decrease farm AMU in the next five years.

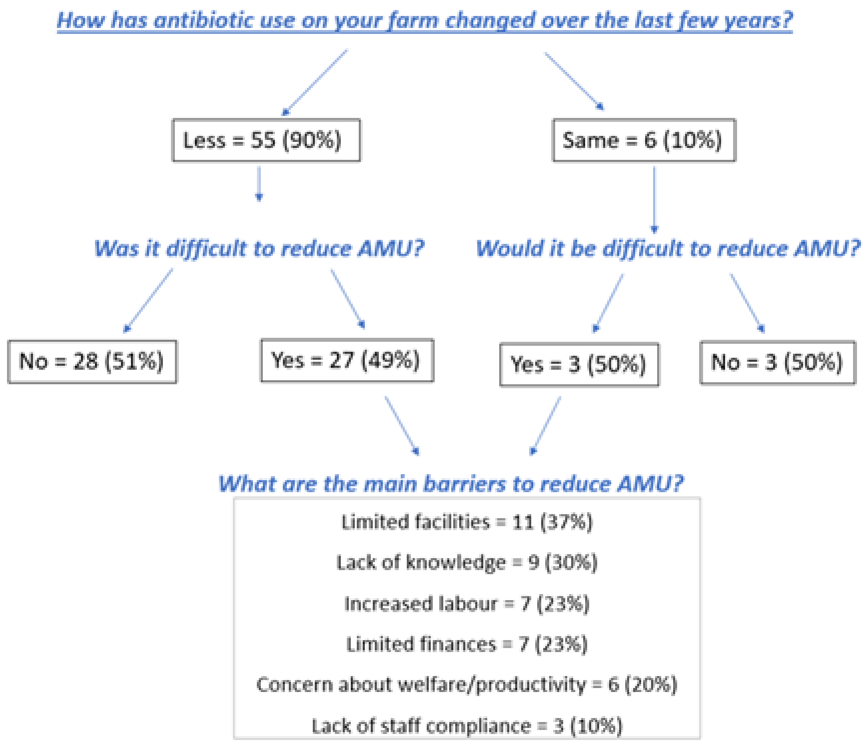

Figure 5 - Antimicrobial usage (AMU) change in the last few years and main barriers associated with reduced AMU for Scottish dairy farmers

When asked to give examples of the practices implemented via an open question, selective dry cow therapy (SDCT) was the most cited (38/55, 69%), followed by improved hygiene and comfort and vaccination. Around 67% reported having written antimicrobial treatment protocols, and 26% planned to introduce them in the future. Having treatment protocols was associated with a higher frequency of veterinarian discussion about AMR ($P < 0.05$, Pearson's chi-squared test). Some farmers reported regularly sampling diseased animals (e.g., faeces or milk) for microbiological culture (23%), with the majority doing it only occasionally (61%). When questioned on reasons for not using culture, 34/47 (72%) indicated results being too slow, 14/47 (30%) doubted the benefits, and 6/47 (13%) claimed frequent inconclusive results. In contrast, only a few answers were related to a cost issue (3/47, 6%). Most farmers (86%) had implemented SDCT, among which eight did not use antimicrobials in any cows at dry-off. Around 7% were planning to introduce SDCT in the future, while the remainder reported no intention to implement it.

Table 4- Results of a survey of Scottish dairy farmers - reported antimicrobial usage (AMU) and practices on farm.

Q	Indicators	Categories	N	%
12	Most frequently used antibiotic	Penicillin	52	85 (52/61)
		Oxytetracycline	6	10 (6/61)
		Ceftiofur	2	3 (2/61)
		Tylosin	1	2 (1/61)
13	Main condition treated with antibiotic	Mastitis	36	59 (36/61)
		Dry cow therapy	13	21 (13/61)
		Calf pneumonia	9	15 (9/61)
		Post-partum disease	4	6 (4/61)
		Calf diarrhoea	2	3 (2/61)
		Lameness	1	2 (1/61)
14	Practices on farm to reduce antibiotic usage	Yes	55	90 (55/61)
		No	6	10 (6/61)
14	Practices to reduce antibiotic usage mentioned in the open question	SDCT[a]	38	69 (38/55)
		Hygiene/comfort	12	22 (12/55)
		Vaccination	7	13 (7/55)
		Probiotics	4	7 (4/55)
		Footbath	2	4 (2/55)
		Milk culture	2	4 (2/55)
15	Antibiotic treatment protocols on farm	Yes	41	67 (41/61)
		No, planning to have in future	16	26 (16/61)
		No and no intention to have	4	7 (4/61)
19	Culture and sensitivity of samples	Regularly	14	23 (15/61)
		Occasionally	37	61 (37/61)
		Never	10	16 (10/61)
19.a	Reason for not using culture and sensitivity regularly	Delay of the results	34	72 (34/47)
		Uncertainty about the benefit	14	30 (14/47)
		Inconclusive results	6	13 (6/47)
		Cost	3	6 (3/47)
20	SDCT[a] implemented on farm	Yes	53	86 (53/61)
		No, considering in the future	4	7 (4/61)
		No and no intention to have	4	7 (4/61)
20	Proportion of cows receiving antibiotic at dry off (open question)	0%	8	13 (8/61)
		1-10%	11	18 (11/61)
		11-10%	11	18 (11/61)
		21-30%	12	20 (12/61)
		40-50%	11	18 (11/61)
		100%	8	13 (8/61)
21	Antibiotic usage change last years	Less	55	90 (55/61)
		Same	6	10 (6/61)
		More	0	0 (0/61)
21.a	Reducing antibiotic usage was difficult	Yes	27	49 (27/55)
		No	28	51 (28/55)
21.b	Reducing antibiotic usage would be difficult	Yes	3	50 (3/6)
		No	3	50 (3/6)

21.a.b	Main barriers to reduce antibiotic usage (open question)	Limited facilities	11	37 (11/30)
		Lack of knowledge	9	30 (9/30)
		Increased labour	7	23 (7/30)
		Limited finances	7	23 (7/30)
		Welfare/productivity concern	6	20 (6/30)
		Lack of staff compliance	3	10 (3/30)
22	Antibiotic usage change next 5 years	Less	53	87 (53/61)
		Same	8	13 (8/61)
		More	0	0 (0/61)

[a] Selective dry cow therapy

Two questions explored the main motivators and concerns associated with decreasing AMU. Minimising antimicrobial residues and meeting milk buyer standards had a major influence on reducing AMU in most of the respondents (75%). Only 36% indicated minimising cost as an important motivator to reduce AMU. Adverse effects on animal health and welfare were the main concerns associated with decreasing AMU. In contrast, potential economic consequences (e.g. decreased profitability, milk production, rising of other costs) were less worrying for respondents.

In the disease scenarios, antimicrobials were most frequently chosen as the first treatment option in cases of calf pneumonia (89%), followed by clinical mastitis (59%) and metritis (56%). Fewer farmers used antimicrobials for cow lameness (20%) and milk drop (e.g., a drop in milk production) (34%), and none for calf diarrhoea. Only approximately 10% of the farmers collected a milk sample before administering antimicrobials for mastitis. Some farmers opted for NSAIDS/fluids as the first treatment in all scenarios, with this proportion particularly high for calf diarrhoea (93%) and cow lameness (48%). The veterinarian consultation was selected by more than half of the participants for the scenario of milk drop and fever (Figure 6).

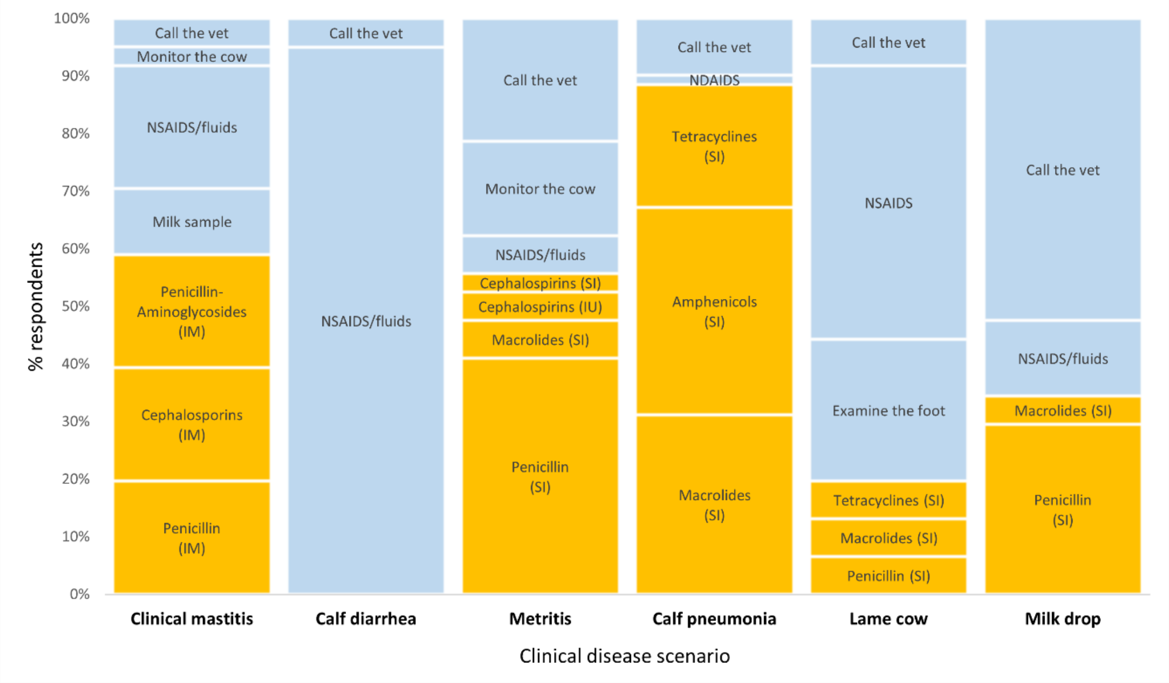

Figure 6 - Proportion of Scottish dairy farmers who opted for antibiotic treatment (yellow) and proportion of Scottish dairy farmers who opted for an alternative to antibiotic treatment (blue) in the clinical disease scenarios

Some best practices were tested in the clinical disease scenarios (Table 1). In the case of clinical mastitis and calf pneumonia, all respondents registered the treatment in the medicine book. While a computer was always used for recording clinical mastitis, it was used by only 13% of the farmers for calf pneumonia. In the case of clinical mastitis and metritis, around two-thirds of farmers did not use the milk of the treated cow to feed calves. Whilst in calf pneumonia approximately 30% of the farmers followed the treatment duration suggested in the farm protocols, this option was not selected for the lame cow scenario, indicating a potential absence of protocols for this clinical condition. In the case of the calf diarrhoea scenarios (scenarios 2 and 5), more than half (69%) isolated the sick animals; however, only 3% and 10% respectively fed them last. Approximately 84% chose to collect a faecal sample for culture. No farmers decided to use a prophylactic treatment in other calves.

Section Three (Farmer Attitudes: towards AMU and concern about AMR)

Figure 7 and Table 5 show the level of agreement with some attitude statements about AMR. Most farmers (89%) believed that reducing AMU on UK dairy farms is important. In comparison, there was significantly less agreement with there being too much reliance on antimicrobials, or with the statement "I am concerned about AMR in the UK dairy farms" (P < 0.001, Kruskal-Wallis). Most participants (82%) agreed that AMU on farms might contribute to the emergence of AMR in livestock. In comparison, there was significantly less agreement on the association with human AMR (P < 0.001, Kruskal-Wallis). These five attitude statements are related to the perception of AMR as a threat (Cronbach's α factor = 0.80). Regarding farmers' perceived ability, about 66% expressed the need for more training to reduce their AMU.

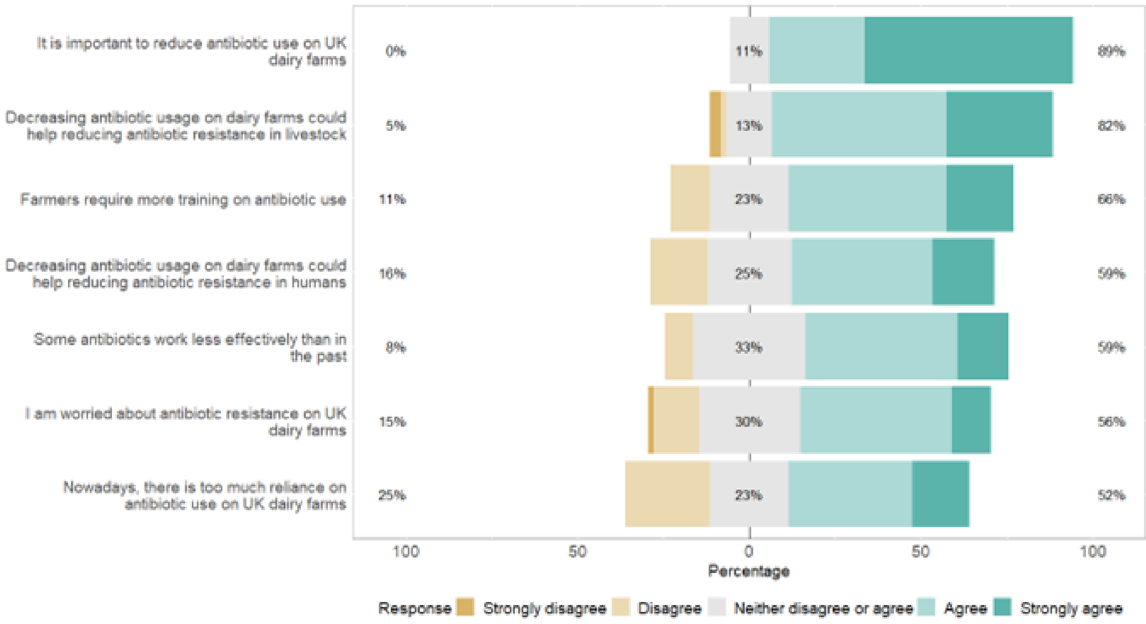

Figure 7 - The level of agreement of Scottish dairy farmers with some staments regarding antimicrobial resistance in dairy farms. The proportions of farmers ranking the level of agreement with each statement as strongly disagree and disagree (scores 1 and 2), neither disagree or agree (score 3) and agree and strongly agree (scores 3 and 4) are indicated (UK, United Kingdom)

Farmers who described a correct definition of AMR expressed more concerns about AMR on UK dairy farms (p < 0.002, Pearson's chi-squared test).

Regarding attitudes towards best practices, the majority of farmers (>90%) agreed on the importance of all best practices presented: keeping records of AMU, respecting the withdrawal period and the prescribed duration of AM treatment, having treatment protocols, implementing farm biosecurity and vaccination to reduce AMU, and having an isolation pen for sick animals. These statements are related to the perception of the importance of best practices for responsible AMU (Cronbach's α factor= 0.75).

Table 5- Results of a survey of Scottish dairy farmers - attitudes towards antimicrobial resistance (AMR) and best practices implementation.

Q	Indicators	Categories	N	%
32	It is important to reduce antibiotic usage on UK[a] dairy farms	Strongly agree	37	61 (37/61)
		Agree	17	28 (17/61)
		Neither agree nor disagree	7	11 (7/61)
		Disagree	0	0 (0/61)
		Strongly disagree	0	0 (0/61)
33	Nowadays, there is too much reliance on antibiotic usage on dairy farms in the UK[a]	Strongly agree	10	16 (10/61)
		Agree	22	36 (22/61)
		Neither agree nor disagree	14	23 (14/61)
		Disagree	15	25 (15/61)
		Strongly disagree	0	0 (0/61)
34	Decreasing antibiotic usage in dairy farms could help reducing antibiotic resistance in livestock	Strongly agree	19	31 (19/61)
		Agree	31	51 (31/61)
		Neither agree nor disagree	8	13 (8/61)
		Disagree	1	2 (1/61)
		Strongly disagree	2	3 (2/61)
35	Decreasing antibiotic usage in dairy farms could help reducing antibiotic resistance in humans	Strongly agree	11	18 (11/61)
		Agree	25	41 (25/61)
		Neither agree nor disagree	15	25 (15/61)
		Disagree	10	16 (10/61)
		Strongly disagree	0	0 (0/61)
36	Some antibiotics work less effectively than in the past	Strongly agree	9	15 (9/61)
		Agree	27	44 (27/61)
		Neither agree nor disagree	20	33 (20/61)
		Disagree	5	8 (5/61)
		Strongly disagree	0	0 (0/61)
37	Farmers require more training on antibiotic usage	Strongly agree	12	20 (12/61)
		Agree	28	46 (28/61)
		Neither agree nor disagree	14	23 (14/61)
		Disagree	7	11 (7/61)
		Strongly disagree	0	0 (0/61)
38	Farm biosecurity and vaccination can reduce antibiotic usage	Strongly agree	29	48 (29/61)
		Agree	27	44 (27/61)
		Neither agree nor disagree	5	8 (5/61)
		Disagree	0	0 (0/61)
		Strongly disagree	0	0 (0/61)
39	It is important to have protocols for antibiotic usage on farm	Strongly agree	28	46 (28/61)
		Agree	29	60 (29/61)
		Neither agree nor disagree	4	6 (4/61)
		Disagree	0	0 (0/61)
		Strongly disagree	0	0 (0/61)

40	It is important to keep treatment records on farm and review antibiotic usage regularly	Strongly agree	41	67 (41/61)
		Agree	20	33 (20/61)
		Neither agree nor disagree	0	0 (0/61)
		Disagree	0	0 (0/61)
		Strongly disagree	0	0 (0/61)
41	It is important to always respect the prescribed duration course of antibiotic	Strongly agree	39	64 (39/61)
		Agree	18	30 (18/61)
		Neither agree nor disagree	4	6 (4/61)
		Disagree	0	0 (0/61)
		Strongly disagree	0	0 (0/61)
42	It is important to have hospital pens to isolate sick animals and avoid the spread of the diseases	Strongly agree	24	39 (24/61)
		Agree	31	51 (31/61)
		Neither agree nor disagree	5	8 (5/61)
		Disagree	1	2 (1/61)
		Strongly disagree	0	0 (0/61)
43	It is important to always respect the withdrawal period of treated animals before slaughter or including the milk in the bulk milk tank	Strongly agree	54	88 (54/61)
		Agree	6	10 (6/61)
		Neither agree nor disagree	1	2 (1/61)
		Disagree	0	0 (0/61)
		Strongly disagree	0	0 (0/61)
44	I am worried about antibiotic resistance on UK[a] dairy farms	Strongly agree	7	11 (7/61)
		Agree	27	44 (27/61)
		Neither agree nor disagree	18	30 (18/61)
		Disagree	8	13 (8/61)
		Strongly disagree	1	2 (1/61)

[a] United Kingdom

2.5. Discussion

Understanding how dairy farmers use antimicrobials, whether they are aware and concerned about AMR, and whether they are willing to change their practices is important for policymakers and farm advisors to develop effective strategies aimed at reducing AMU.

This study indicated that participants' knowledge about antimicrobials and AMR was variable. Proper AMU and the significance of AMR might still be unknown for some dairy producers. Similar to the UK general population (Hawkins et al., 2022), approximately one-third of the farmers believed that antibiotics could be used to treat virus infections. Only 34% reported an accurate definition of AMR, a smaller proportion than previously indicated by an English dairy farmers' survey where 55% provided a correct description of AMR (Higham et al., 2018). The difference may be due to a stricter interpretation in our study, as only the definition of AMR as "bacteria developing resistance to antimicrobials" was considered correct. Despite the description given by some respondents as a "loss of efficacy of antibiotics" cannot be regarded as false, this represents a consequence of AMR and is not a correct definition.

Our study found that reported awareness of RUMA guidelines was higher than previously found by Jones et al in a 2013 survey of English and Welsh producers (Jones et al., 2015). A potential explanation may be a trend for farmers to be more exposed to AMU restrictions and regulations in recent years, although this may not translate into knowledge. Farm owners' familiarity with the guidelines was greater than dairy herd managers. Farm employees are often the main ones responsible for administering antimicrobials, particularly in large-size herds. Our results suggest that in addition to the need for campaigns regarding responsible AMU in the Scottish dairy sector, knowledge and awareness should be disseminated consistently among all stakeholders handling antimicrobials. For instance, dairy managers should be involved in the farm AMU monitoring and the decision-making process of antimicrobial treatment protocols with the herd's veterinarian. Also, farm employees involved with AMU should be encouraged to participate in responsible AMU training, such as the one certified by the Red Tractor (Red Tractor, 2021).

Farmers' implementation of advice depends on who delivers the recommendation (Bard et al., 2019). Similar to previous studies (Friedman et al., 2007; Jones et al., 2015; Swinkels et al., 2015; Golding et al., 2019; Doidge et al., 2020), this survey shows that herd veterinarians are regarded as the most reliable source of information and the most influencing social referent. However, we found that discussions about AMR with the veterinarian were infrequent. For half of the respondents, it happens once a year, likely at the AMU review required by the Red Tractor Assurance, a UK food and farm standard voluntary scheme guaranteeing food safety, traceability, and animal welfare across livestock species (Red Tractor, 2021). The lack of communication around AMR may be due to the infrequent contact with veterinarians, as suggested by our results and other studies (Jones et al., 2015; Fischer et al., 2019). Also, it could be linked to veterinarians' perceptions that dairy producers are reluctant to change their practices (Higgins et al., 2017; Golding et al., 2019), and to veterinarians' time limitations (Llanos-Soto et al., 2021). Since veterinarian recommendations have the most decisive influence on farmers' behaviour, practitioners must be aware of their role in tackling AMR and should dedicate part of their work to this purpose. According to research conducted in the UK, despite antimicrobial stewardship principles being included in most undergraduate veterinary schools, there is still room for improvement in students' education in this area (Castro-

Sánchez et al., 2016). Enhancing future veterinarians' education is important to improve their prescribing behaviour and provide them with the skills to engage farmers in the fight against AMR. Also, continuing professional development (CPD) courses on this topic, including aspects of social science, may help practitioners to facilitate changes on farms.

Our results suggest that farmers tend to rely on personal experience when choosing antimicrobials and veterinarians are consulted only occasionally, although they are considered trusted advisors. The widespread implementation of written AMU protocols may partially explain this finding. Similarly, in previous studies, farmers reported relying significantly on pre-existing experiences and some even more than on veterinarians' advice (McDougall et al., 2017; Ekakoro et al., 2019). Repeated positive outcomes of some antimicrobials may lead farmers to have preferred treatments that they consider more effective. Ritualising drug choice is likely to act as a barrier to farmers' responsible AMU, as behavioural interventions are more difficult when there is an over-reliance on previous experiences (Skjølstrup et al., 2021). Farmers are reluctant to implement new recommendations if they do not believe they are practical and feasible (Ritter et al., 2017). Therefore, it is essential to educate and promote the effectiveness of alternative and responsible practices to change deeply embedded behaviours. Strategies, such as showing results in other dairy farms, may help farmers to change their perceptions (Bard et al., 2019).

Previous research on dairy farmers' AMU behaviour highlighted the importance of external approval and social norms conformity (Jones et al., 2015; Scherpenzeel et al., 2016; Richens et al., 2018; Fischer et al., 2019). Unlike other surveys (Swinkels et al., 2015; Fischer et al., 2019), farmers in our study did not express the need to be considered a "good farmer" by other producers and did not feel pressured by peers' opinions (e.g., colleagues, family, and other farmers). Gerber and colleagues reported similar results (Gerber et al., 2020), with most participants not motivated by other farmers to reduce their AMU. On the other hand, we found that farmers valued the opinion of some social referents in the dairy industry (e.g., milk buyers and consumers), and minimising residues and meeting milk buyer standards were the main drivers for lower AMU. Although some farmers may feel constrained by public demand for antibiotic-free products and the negative perception of the industry (Swinkels et al., 2015; Fischer et al., 2019), our results suggest a positive impact of consumer pressure in shaping and improving AMU in livestock. Since consistent findings were reported in other UK studies (Jones et al., 2015; Golding et al., 2019), farmers' attitudes towards consumers likely depend on the agricultural framework of the country.

Farmers indicated mastitis as the main reason for AMU and penicillin as the most used antimicrobials, also reported by previous studies in the UK and Scotland (Higham et al., 2018; Humphry et al., 2021). Instead, in the scenarios section, we found that antimicrobials were most frequently chosen as a treatment option in calf pneumonia, followed by clinical mastitis. None of the respondents used antimicrobials for the diarrhoea calf scenario as a first-line treatment, suggesting a much lower AMU for this condition than in UK beef calves (Doidge et al., 2020). The different finding may be due to more extensive production in the beef sector, with less veterinarian contact and antimicrobial treatment protocols.

This survey showed that most farmers had already taken steps to reduce AMU: around 90% had practices implemented on farms, with SDCT being the most cited. The presence of antimicrobial treatment protocols was widespread among participants, and generally, these were more popular than in other studies (Falkenberg et al., 2019; Schwendner et al., 2020). This may be explained by the larger size of the Scottish herds compared to other EU countries and by the compulsory requirement set by some UK milk buyers (Farm Advisory Service, 2022). Culture and sensitivity of biological samples from diseased animals (e.g., faeces and milk) was reported to be used only occasionally and to a lesser extent than in other countries (Schwendner et al., 2020). Interestingly, lab costs were a limiting factor for only a few farmers, whereas the main reason for not using this practice was the delay in the results. The clinical disease scenarios suggested that producers were more likely to collect a biological sample for culture in case of a disease outbreak (e.g., calf diarrhoea) rather than for diagnostic testing in an individual animal infection (e.g., mastitis). Clinical mastitis is usually treated symptomatically without knowing the aetiology, making administering antimicrobials often unnecessary (Ruegg, 2021). Research reports that *E. coli* udder infection commonly cures spontaneously, 19-46% of clinical cases of mastitis are microbiologically negative, and some pathogens (e.g., yeasts, Serratia spp. etc.) do not respond to antimicrobial treatments (Krömker and Leimbach, 2017). Therefore, many cases of non-severe clinical mastitis would not benefit from antimicrobial therapy (De Jong et al., 2023). Farmers need to be trained to identify more precisely which animals require antimicrobial treatment and to ensure evidence-based AMU. Newer point-of-care diagnostics may overcome some of the limitations of classic laboratory tests and offer more rapid results (Buller et al., 2020).

Our study suggests that feeding waste milk to calves is still widespread in Scotland. For instance, in two clinical disease scenarios (mastitis and metritis), approximately 30% of the farmers reported feeding milk to calves following antimicrobial administration to those cows. This practice seems to be reduced compared to past years in the UK (Brunton et al., 2012; Higham et al., 2018) or compared to other countries (Gosselin et al., 2022), but it still represents a potential risk for AMR emergence. Indeed, studies exploring the impact of feeding milk containing antimicrobial residues to calves demonstrated the selection of antimicrobial-resistant bacteria (Jarrige et al., 2020; Firth et al., 2021).

As a result of the initiatives and awareness-raising actions proposed by the government and international organisations, antimicrobial sales in livestock have decreased over the last decade (Veterinary Medicine Directorate, 2021). The most recent version of the UK Veterinary Antibiotic Resistance and Sales Surveillance (UK-VARSS, 2021) reported a reduction of 68% in cattle injectable HP-CIAs between 2016 and 2020 (Veterinary Medicine Directorate, 2021). Almost all participants of this study (90%) reported having reduced their AMU in previous years, indicating a more promising result than Jones et al, where only 37% of respondents indicated a less frequent AMU compared to the previous year (Jones et al., 2015). Nevertheless, many farmers believed that reducing AMU was complicated, with limited facilities (e.g., lack of isolation pen for sick animals, inadequate space allowance leading to high stocking density) and knowledge of appropriate AMU being the main barriers. Also, they indicated time and budgetary constraints as important limitations to decreasing AMU. For instance, being unable to guarantee proper hygiene practices due to time and workforce shortage (e.g., cleaning, bedding, regular mastitis detection) and poor financial means to reinvest in disease prevention (e.g., housing, ventilation). Other studies reported that economic constraints, tight profit margins, and inadequate facilities hinder farmers from improving herd health and reducing AMU (Friedman et al., 2007; Fischer et al., 2019; Golding et al., 2019). Since producers may be discouraged by financial limitations, advisors must demonstrate the effectiveness of simple, low-cost hygiene/management practices to prevent infections. Also, economic rewards and incentives for low antimicrobial users may motivate farmers to implement new strategies and optimise AMU (McKernan et al., 2021).

Regarding future intention, 87% reported planning to decrease AMU in the next five years. Once more, this proportion is higher compared to previous UK studies (Higham et al., 2018; Jones et al., 2015), suggesting that recent antimicrobial stewardship campaigns (e.g., RUMA Targets task force) had positive impacts on farmers' intentions (RUMA, 2017).

Understanding farmers' attitudes toward AMR is essential to implement specific strategies and achieving responsible AMU. In our survey, we found a wide variety of attitudes, with up to 25% of respondents disagreeing with some of the statements regarding AMR. These results suggest that farmers' awareness of AMR is varied and complex, and veterinarians and advisors should consider this before recommending interventions. Tailored strategies would be more beneficial than a generic approach, as each producer's willingness to reduce AMU is different (Speksnijder and Wagenaar, 2018). For instance, farmers arguing the global health consequences of AMR and with no intention to decrease farm AMU would benefit first further education on the subject and awareness-raising initiatives. In contrast, other farmers may be receptive to more in-depth AMU practice changes. In this study, most respondents (approximately 90%) endorsed the importance of decreasing AMU on UK dairy farms. However, this finding conflicts with the fact that only half of them agreed on the over-reliance on antimicrobials, or expressed concerns about AMR. Then, for some farmers, there may be a mismatch between the intention to reduce AMU and the actual recognition of over-using antimicrobials. As suggested by other studies in the UK (Golding et al., 2019; Helliwell et al., 2019), this may indicate that dairy producers do not perceive AMR as a current risk for their farm or something they have already experienced. Instead, they may be more concerned about daily challenges, such as welfare, poor housing conditions, and productivity (Skjølstrup et al., 2021). Respondents generally agreed on the association between AMU and AMR in livestock. However, a smaller proportion acknowledged the potential impact of dairy cattle AMU on global health. Scepticism about the contribution of AMU in cattle to human AMR was reported in other studies (Raymond et al., 2006; Ekakoro et al., 2019; Golding et al., 2019). Renunciation of responsibility can be an important barrier to improving AMU on dairy farms. It is difficult to convince farmers to change their practices if they ignore the adverse effects of imprudent AMU. Raising awareness about the potential risk of AMR for global health may be an effective strategy to influence farmers' AMU behaviour. Indeed, we found that farmers lacking knowledge regarding AMR meaning expressed fewer concerns about AMR.

Many farmers in this study believed that more training is essential for reducing AMU. Self-efficacy, or perceived behavioural control, depends on a person's belief that they are able to accomplish a task (Ritter et al., 2017; Skjølstrup et al., 2021). If farmers believe they possess the knowledge and the skill to achieve reduced AMU, they would be more likely to overcome habitual behaviour and implement new strategies. This study highlights the importance of providing dairy producers with the tools they need to reach responsible AMU, such as regular training on prudent AMU and antimicrobials administration, guidance from veterinarians or external advisors, and assessment of the outcomes (e.g., regular farm AMU monitoring and review of the goals achieved).

Several limitations may have influenced the results of this study. Self-selection bias due to voluntary participation in the online survey was possible, with overrepresentation of farmers with a particular interest in the topic or a higher educational level. Farmers that had experienced issues with lack of efficacy of antimicrobials may have been more motivated to participate. We noted that 33% of respondents had a university degree; however, we were unable to access data to verify whether the educational level of respondents was representative of Scottish dairy farmers. Participants not involved in antimicrobial administration may not have been fully aware of the practices and AMU on the farm. All farmers in this study were working with milking cows, suggesting that these results may not apply to different dairy sectors, such as heifer rearing farms. In the survey, social desirability bias may happen when respondents give socially accepted answers that do not guarantee the truth. In this study, anonymity was guaranteed, so social desirability bias was likely limited. Despite a low response rate, as expected for non-random online surveys, the sample represented a good proportion of the targeted group (Scottish dairy farmers). Regarding the design of the survey, many of the questions (e.g., attitudinal statements, clinical scenarios) were based on focus group/workshop findings and on authors' experience, which may have introduced bias.

This survey represents the first time that practices and knowledge around AMU and AMR have been investigated in the Scottish dairy sector. The results show that significant progress has been achieved regarding AMU and best practices implementation (e.g., SDCT, discarding waste milk) when comparing the results to previous UK surveys (Brunton et al., 2012; Higham et al., 2018). Yet, awareness and attitudes towards AMR varied among farmers. To help veterinarians and advisors tackle AMR in Scottish dairy herds, future research should focus on identifying the factors influencing farmers' intentions to reduce AMU.

Chapter 3 - Factors influencing Scottish dairy farmers' antimicrobial usage, knowledge and attitude towards antimicrobial resistance

Published in "Preventive Veterinary Medicine". Reference:

Borelli, E., Ellis, K., Pamphilis, N.M., Tomlinson, M. and Hotchkiss, E., 2023. Factors influencing Scottish dairy farmers' antimicrobial usage, knowledge and attitude towards antimicrobial resistance. Prev. Vet. Med. p.106073.

3.1. 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. The survey was designed based on the findings of two focus groups and was disseminated online via multiple ways (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 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 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 fewer educational qualifications. This study can inform the development of educational initiatives to encourage responsible AMU on dairy farms.

3.2. 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 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 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 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 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' increased AMR knowledge and positive attitudes to reducing AMU may help to encourage behavioural change 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.

3.3. Materials and methods

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) (Appendix III). 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 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.

The survey design was guided by 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 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 of 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 antibiotics.

Statistical analysis

Survey answers were downloaded and organised in a datasheet in Microsoft Excel. All statistical analyses were performed in R studio. 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 (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.

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 6).

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 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 6. 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 was determined by averaging the degree of farmers' agreement/disagreement with five 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.

Table 6 - 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?	Tot. score 0: 14 (23%) Tot. score 1: 16 (26%)	Unsatisfactory knowledge: 30 (49%)

	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 2: 24 (39%) Tot. score 3: 7 (12%)	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)	Tot. score 0: 3 (5%) Tot. score 1: 12 (20%)	High user: 15 (25%)
	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	Tot. score 2: 17 (28%) Tot. score 3:16 (26%)	Medium user: 33 (54%)
	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 4: 11 (18%) Tot. score 5: 2 (3%) Tot. score 6: 0 (0%)	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?	Av. Score 2.5-3.0: 8 (13%) Av. Score 3.1-3.4: 8 (13%)	Neutral attitude: 16 (26%)
	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	Av. Score 3.5-4.0: 25 (41%) Av. Score 4.1-4.4: 9 (15%)	Positive attitude: 34 (56%)
	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 4.5-5.0: 11 (18%)	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 %.

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.

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.

3.4. 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 is 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).

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 7).

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 8).

Table 7 - K-means clusters[1] of 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

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 8 - K-means clusters[1] of the factors influencing the antimicrobial choice of Scottish dairy farmers

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

[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

Farmers' knowledge of antimicrobials and AMR

Table 9 shows the predictor variables used for the model of farmers' knowledge of antimicrobials and AMR. The final logistic regression results are presented in Table 10. 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.

Table 9 - 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)		X	X	X

Conventional	57 (93%)			
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 6)				
Satisfactory	31 (51%)		X	X
Unsatisfactory	30 (49%)			
Attitude (Table 6)				
Neutral	16 (26%)			
Positive	34 (56%)		X	
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 10 – Final logistic regression analysis of factors associated with satisfactory knowledge (vs. unsatisfactory knowledge) about antimicrobials and antimicrobial resistance among 61 Scottish dairy farmers

Predictor of farmers' knowledge	Coeff	SE	OR	OR 95 % CI	P value
Education degree					
Secondary school	Referent		-	-	-
University	3.34	0.89	28.28	4.72-169.35	<0.001
Source of AMU information used					
Vet and other info	Referent		-	-	-
Vet info	1.47	0.78	4.42	1.04-18.13	<0.05
Livestock farmed					
Only dairy	Referent		-	-	-
Other livestock (beef/sheep)	1.57	0.69	4.82	1.19 -19.47	<0.05

Notation: AMU = Antimicrobial usage

Farmers' AMU behaviour

Table 9 shows the predictor variables used for the model of farmers' AMU behaviour. The final ordinal regression model results are presented in Table 11. 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.

Table 11 - Final ordinal regression analysis of factors associated with low antimicrobial usage (in the survey clinical disease scenarios) among 61 Scottish dairy farmers

Predictor of farmers' AMU behaviour	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

Notation: AMU = Antimicrobial usage

Farmers' attitudes towards AMR

Table 9 shows the predictor variables used for the model of farmers' attitudes towards AMR. The final ordinal regression model results are presented in Table 12. 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.

Table 12 - Final ordinal regression analysis of factors associated with positive attitudes towards antimicrobial resistance mitigation among 61 Scottish dairy farmers

Predictor of farmers' attitude	Coeff	SE	OR	OR 95 % CI	P value
Farm type					
Conventional	Referent		-	-	-
Organic	2.91	1.22	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

3.5. Discussion

Antimicrobial resistance has been described as one of the most severe global threats of this century (WHO, 2021). Since the transmission of antimicrobial-resistant microorganisms between animals and humans has been documented (Tang et al., 2017), a multidisciplinary approach involving a wide range of stakeholders is paramount to combat AMR. For this reason, 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.

Despite risk perception being complex and related to several factors, farmers' misconceptions about AMR can lead to the underestimation of its threat and drive antimicrobial misuse (Skjølstrup et al., 2021). For these reasons, identifying the factors influencing producers' awareness of responsible AMU and AMR is key to reducing the risk of AMR emergence on dairy farms. In this survey, respondents holding a university degree demonstrated better knowledge of antimicrobials and AMR. The same finding was reported by surveys carried out in other countries (Alhaji et al., 2019; Ozturk et al., 2019; Dankar et al., 2022). The association likely results from increased comprehension of the mechanisms behind antimicrobial activity and bacteria resistance in respondents with higher education attainment. This finding suggests that 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 producers holding higher academic qualifications represent a small proportion of the Scottish dairy sector. For instance, in a recent study, approximately 20% of Scottish dairy farmers held a university degree (Shortall and Lorenzo-Arribas, 2022). 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. The dairy industry and farmers' organisations should collaborate to shift misconceptions about farming and bring qualified and knowledgeable workforces into the dairy industry.

In contrast to our results, other studies found that younger farmers were more likely to have better knowledge of antimicrobials and AMR (Kramer et al., 2017; Ozturk et al., 2019). The difference could be explained by the lack of association between education degree and age in our survey, which in the other studies may have confounded the association with the level of knowledge. On the other hand, we found that young producers (<35 years old) reported higher AMU in the scenarios compared to their older colleagues (>51 years old). 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. This result indicates that recently employed farmers would benefit from specific training on how to identify more precisely animals requiring AMU.

In our survey, veterinarians were considered the most trustworthy source of information. Farmers using with confidence "only veterinarian information" had greater knowledge than farmers also relying on other sources such as milk buyers, the web and farming articles. The importance of veterinarians' role in raising AMR awareness among dairy framers 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. Practitioners in the UK believed workshops and discussion sessions might be efficient tools to disseminate AMU knowledge and build successful veterinarian-farmer collaboration (Higgins et al., 2017).

As supported by previous literature, our results showed that farmers' AMU decision-making is mostly influenced by their own previous AMU experience and veterinarian recommendations (Farrell et al., 2021; Doyle et al., 2022). Moreover, we found that respondents with less consideration for economic factors in antimicrobial choice (e.g., antimicrobial withdrawal period and cost) indicated a lower AMU in the clinical scenarios. 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 persuade them of the possibility of maintaining farm profitability with limited AMU. At the same time, decreasing the financial pressure on dairy herds would likely reduce imprudent AMU and encourage behavioural change, as farmers reported feeling constrained by the system which requires cheap milk and production intensification (Golding et al., 2019). Indeed, Jones et al. (2015) found that those receiving a more significant income from sold milk were more likely to demonstrate a positive intention to reduce their reliance on antimicrobials.

In this study, we found that farm size was positively associated with AMU in the clinical scenarios section. 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). It is also challenging to guarantee responsible AMU when a large number of staff, with different levels of knowledge and skills, are responsible for animals' health and treatments. In this regard, antimicrobial treatment protocols are a valuable tool to improve diagnostic specificity and refine AMU (Uyama et al., 2022). 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). Ritter et al. (2017) identified perceived responsibility as a major player in dairy farmers' implementation of recommended strategies and behaviour change. Significant concerns about consumers' health and industry expectations may provide organic farmers with a sense of ownership to tackle AMR. On the other hand, it is possible that farmers with particular interests or attitudes are more likely to be involved with organic production systems.

Respondents breeding livestock other than dairy cows (e.g., beef and sheep) expressed better AMR and AMU knowledge than dairy-only farmers. Recently, Doidge et al. (2020) reported that 90% of UK beef farmers in their study were aware of the meaning of AMR. The level of awareness was self-reported and not assessed by the authors, and since there is usually a significant gap between self-reported and actual knowledge of farmers (Higham et al., 2018), it is difficult to speculate different levels of awareness among farming sectors. Nevertheless, respondents 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, and this might enhance their general comprehension of drug resistance.

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, uncertainty about their abilities, 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 low number survey 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. The low number of respondents in some groups may have biased the significance of some associations (e.g., organic farmers and farmers with an university degree). 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.

3.6. Conclusions

This survey provides insights into the factors influencing Scottish dairy farmers' knowledge and perceptions of AMR and AMU. 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.

Chapter 4 – Discussion

4.1. General discussion

In light of antimicrobial resistance (AMR) being acknowledged as a critical global threat (World Health Organisation, 2021), and the evidence on the potential transmission of antimicrobial-resistant microorganisms between animals and humans (Tang et al., 2017), a multidisciplinary approach involving various scientific expert is crucial to combat AMR.

Over the past decade, a lot of effort has been made to explore antimicrobial usage (AMU) in agriculture and farmers' attitudes to reduce their reliance on antimicrobials. Indeed, in order to design effective strategies aimed at reducing AMU, policymakers need to comprehend how dairy farmers use antimicrobials, their awareness and concern regarding AMR, and their willingness to change their behaviour. However, a knowledge gap of these behavioural and attitudinal factors exists in the literature. The first part of this study describes Scottish dairy farmers' awareness, beliefs, and intention to reduce the risk of AMR emergence. In addition, it provides insight into how AMU best practices are implemented and antimicrobials are used. The second part of the study aimed to identify some factors driving the knowledge, behaviour, and attitudes of dairy farmers towards AMU and AMR.

4.2. Dairy farmers’ knowledge and awareness of AMR

In this study, there was no significant association between dairy farmers’ knowledge of AMR and antimicrobials and their behaviour related to AMU. However, according to a recent systematic review of knowledge, attitudes, perceptions, and behaviours of dairy farmers and veterinarians regarding AMR, increasing knowledge and awareness are recommended strategies to promote appropriate AMU behaviour among dairy producers (Farrell et al., 2021). Additionally, in another systematic review, the importance of educating farmers was highlighted as it was proved to enhance responsible AMU (McKernan et al., 2021). Therefore, scientific evidence supports the need to increase farmers’ awareness of their role in tackling AMR. The lack of association between knowledge and behaviour in our study may be explained by the fact that farmers face difficulties putting their knowledge into practice and implementing recommended changes.

Limited resources such as proper stockmanship, finances, and farm facilities can pose a challenge in translating technical knowledge into action. In addition, other concerns related to profitability and animal welfare can negatively affect producers' motivation to reduce AMU (Speksnijder and Wagenaar, 2018). In fact, farmers are more likely to invest their time and resources in issues that they perceive as directly affecting their business and may be less interested in questions which are considered far from their reality (Ritter et al., 2017).

The results of this study indicated that a significant proportion of participants lacked knowledge about antimicrobials and AMR. For instance, 31% believed that antibiotics are effective against virus infection and 25% thought that they can be used to treat parasite infestation. A study conducted among the UK general population reported similar findings (Hawkins et al., 2022). This suggests that dairy farmers, despite having access to and regularly administering antimicrobials to animals, may not be more informed about proper AMU than the average population. Approximately one-third of the respondents were not aware of the meaning of AMR. Due to a strict interpretation of the answers, it is possible that some of the responses were erroneously classified as incorrect, as we considered as accurate only interpretations of AMR referable to "bacteria developing resistance to antimicrobials". However, a significant proportion of farmers (28%) thought that AMR was developed by animals, suggesting a poor comprehension of this global issue. Inadequate farmers' knowledge of antimicrobials and AMR represents an important risk for AMR emergence in agriculture and should be regarded as an important future area of improvement. In a recent Irish survey, dairy farmers showing greater awareness of AMR were more likely to implement selective dry cow therapy (SDCT) (Farrell et al., 2023), suggesting that interventions aimed at promoting behavioural change should incorporate efforts to increase producers' knowledge awareness of AMR. Consistent dissemination of knowledge and awareness regarding responsible AMU seems essential for improving AMU practices in the Scottish dairy sector. To support this idea, our results indicate that a significant number of farmers believed that additional training is crucial to decrease their AMU. Likely, dairy producers perceive a lack of competence in implementing AMU reduction measures at the farm level. Some authors suggested the concept of self-efficacy, or perceived behavioural control, as an important factor to consider in behavioural change programmes (Ritter et al., 2017; Skjølstrup et al., 2021). This theory used in psychology and social science explains how people's beliefs about their own capabilities influence their motivation and behaviour. In other words, if someone perceives that they have the necessary skills and resources to accomplish a task, they are more likely to attempt it and succeed. The lack of awareness of dairy farmers, but their coexisting willingness to improve their skills, highlight the importance of providing dairy producers with the tools they need to reach responsible AMU, such as regular training on prudent AMU and antimicrobials administration, guidance from veterinarians or external advisors, and assessment of the outcomes (e.g., regular farm AMU monitoring and review of the goals achieved).

In this survey, individuals who possessed a university degree exhibited greater knowledge of AMR and proper AMU. This finding has been previously reported (Alhaji et al., 2019; Ozturk et al., 2019; Dankar et al., 2022) and might lead to different interpretations. On the one hand, it suggests that it would be beneficial to target regular training on responsible AMU and AMR to farmers with lower levels of education. On the other hand, it is possible that engaging people with higher academic qualifications would enhance AMR awareness and prudent AMU. In addition, we found a significant association between respondents' level of AMR and AMU awareness and their farm system. Farmers breeding livestock other than dairy cows (e.g., beef and sheep) expressed better knowledge than dairy-only farmers. A potential explanation might be that farmers' working with different food-producing animals are exposed to various AMR education campaigns, training and advisors. In addition, the current emergence of anthelmintic resistance could potentially improve sheep farmers' understanding of drug resistance.

Regarding the knowledge of best practices recommendations, most of the farmers were aware of RUMA guidelines on responsible AMU and farm owners reported greater familiarity compared to dairy herd managers. In the UK, particularly in large herds, farm employees are often responsible for administering antimicrobials and therefore their lack of awareness about AMU best practices may represent a great risk for AMR. For this reason, it is important to ensure that all stakeholders are involved in AMU training, farm AMU monitoring and decision-making process with the herd's veterinarian. In addition, farm employees should be encouraged to participate in responsible AMU training, such as the training certified by the Red Tractor (Red Tractor, 2021).

4.3. Social influence on farmers' behaviour and veterinarians' role

Earlier studies investigating the AMU behaviour of dairy farmers have emphasized the significance of conforming to social norms and obtaining external validation (Jones et al., 2015; Scherpenzeel et al., 2016; Richens et al., 2018; Fischer et al., 2019;). According to our survey, herd veterinarians are considered the most trustworthy source of information and have the greatest social influence on farmers' behaviour. In addition, we found that farmers who solely relied on information from veterinarians had higher levels of knowledge compared to those who also consulted other sources such as milk buyers, the web, and farming articles. The importance of veterinarians' role in raising AMR awareness has been highlighted in several similar studies in the UK and abroad (Friedman et al., 2007; Jones et al., 2015; Swinkels et al., 2015; Golding et al., 2019; Doyle et al., 2022).

Despite this, we found that discussions about AMR with the veterinarian were occasional. This may be due to the infrequency of veterinarians' visits as farmers often treat animals autonomously, to veterinarians' time limitations, or to the perception that dairy producers are reluctant to change their practices (Higgins et al., 2017; Golding et al., 2019). Recently, Grondal et al. indicated that AMU reduction can be a source of disagreement and conflict between farmers and veterinarians, even within a well-established relationship (Gröndal et al., 2023). It is possible that in certain cases veterinarians choose to avoid discussing AMR in order to preserve their relationship with the client.

Therefore, although veterinarians are expected to play a proactive role in the fight against AMR, they may face challenges in doing so. Participating in continuing professional development (CPD) courses that cover topics related to social science and AMR may assist practitioners in facilitating changes on farms. Also, improving the education of upcoming veterinarians is crucial for promoting responsible prescribing practices and equipping them with the necessary abilities to involve farmers in combating AMR. A study conducted in the UK has shown that although most undergraduate veterinary schools cover antimicrobial stewardship principles, there is still a need for further improvement in educating students on this topic (Castro-Sánchez et al., 2016). Practitioners must be aware of their role in tackling AMR and should dedicate part of their work to this purpose.

Unlike other surveys (Swinkels et al., 2015; Fischer et al., 2019), farmers did not indicate a desire to be recognized as a "good farmer" by their peers, nor did they feel influenced by the opinions of other external people (e.g., colleagues, family, and other farmers). In contrast, we observed that certain social referents in the dairy industry, such as milk buyers and consumers, held significant influence. In fact, important factors motivating farmers to reduce AMU were minimizing residues and meeting milk buyer standards. It has been previously suggested that dairy farmers might feel limited by the public's expectation for antibiotic-free products and the unfavourable perception of the industry (Swinkels et al., 2015; Fischer et al., 2019). However, our results and previous findings suggest that consumer pressure may have a beneficial effect on shaping and enhancing AMU practices among UK dairy farmers, likely due to the agricultural policies and framework of the country (Jones et al., 2015; Golding et al., 2019).

4.4. Antimicrobial usage

The implementation of SDCT greatly enhanced responsible AMU in the dairy industry. A large proportion of the respondents of this survey (86%) reported using SDCT, with 13% not administering antimicrobials in any of the dry cows. This represents important progress in the UK when compared to the findings of Brunton et al. (2012), who found that 85% of the farmers were applying a BDCT to all cows.

In the clinical disease scenarios, we found that antimicrobials were most frequently chosen as a treatment option in calf pneumonia, while none of the respondents used antimicrobials for the diarrhoea calf scenario as a first-line treatment. In recent years, producers have been instructed to not use antimicrobials in non-severe cases of calf diarrhoea as often the aetiology involves viral and protozoal agents, not responding to AMU (Constable, 2009), and bacteraemia is uncommon in calves without systemic signs (Garcia et al., 2022). The widespread implementation of AMU protocols among our respondents may explain this finding, as usually the treatment of non-severe calf diarrhoea involves other treatments (e.g., anti-inflammatory and rehydration fluids). Indeed, we found that antimicrobial treatment protocols were more popular than in other studies (Falkenberg et al., 2019; Schwendner et al., 2020). This may be explained by the larger size of the Scottish herds compared to other European countries and by the compulsory requirement set by some UK milk buyers (Farm Advisory Service, 2022)

Almost all participants of this study (90%) reported having reduced their AMU in previous years, and 87% reported planning to decrease AMU in the next five years. This finding suggests that recent antimicrobial stewardship campaigns (e.g., RUMA Targets task force) and the requirement compelled by milk buyers and farm assurance scheme (e.g., Red Tractor) had positive impacts on farmers' AMU behaviour and intentions to reduce AMU (RUMA, 2017). The last report of the UK Veterinary Antibiotic Resistance and Sales Surveillance (UK-VARSS, 2021) indicated a reduction of 68% in injectable HP-CIAs in cattle between 2016 and 2020 (Veterinary Medicine Directorate, 2021).

Despite most of the farmers achieving a farm AMU reduction in the last years, around 50% thought that it was a difficult process. The main barriers reported were limited facilities to isolate sick animals or to ensure adequate animal space allowance, and a lack of knowledge about antimicrobials. Financial constraints were also reported to be limiting responsible AMU. Indeed, we found that respondents with less consideration for economic factors in antimicrobial choice (e.g., antimicrobial withdrawal period and cost) were more likely to indicate a lower AMU in the clinical scenarios. Many other studies reported that tight profit margins can hinder farmers from maintaining good animal health and preventing infectious diseases (Friedman et al., 2007; Fischer et al., 2019; Golding et al., 2019). In certain instances, farmers may face limitations due to restricted financial resources, which can impede their ability to make essential investments in adequate housing, ventilation systems, and the employment of staff to uphold hygiene standards, ensure adequate nutrition, and detect diseases. In addition, it is possible that producers experiencing financial challenges may prioritise enhancing productivity over combating AMR when making decisions regarding animal treatment. Orpin (2017) reported that many dairy farmers feared that not administering antimicrobials would reduce profitability. As a result, veterinarians and advisors should prioritize the assessment of each farm's financial situation and offer tailored recommendations accordingly. In fact, when producers have financial constraints, advisors should focus on cost-effective hygiene and management practices to prevent infections and limit the administration of antimicrobials. It is equally important to convince them that maintaining farm profitability is possible even with limited AMU, balancing the economic impact with the need for effective treatment. In addition, relieving the financial burden on dairy herds would likely result in a reduction of inappropriate AMU and facilitate the adoption of responsible behaviours (Golding et al., 2019).

In this survey, AMU in the clinical disease scenarios was also influenced by farmers' age, with young producers (<35 years old) reporting higher AMU compared to their older colleagues (>51 years old). The lack of experience with infectious diseases in dairy cattle and the concerns about potential expenses related to animal losses might encourage younger farmers to employ antimicrobials as a strategy to risk-avoidance strategy. In addition, inexperienced farmers may feel pressured to provide immediate solutions and alleviate animal suffering, as antimicrobials are often seen as a rapid and effective way to address infections. For this reason, it is important to provide education and support to inexperienced and recently employed farmers to ensure optimal and judicious usage of antimicrobials on farms. This finding suggests that newly employed farmers could benefit from additional training to improve their ability to accurately identify animals that truly require AMU.

Farm size was also positively associated with AMU in the clinical scenarios section. Several reasons could explain this finding. First of all, the increased density of the livestock population has been often associated with increased spread of infections and infectious disease prevalence, leading to a higher demand for antimicrobials (Velasova et al., 2017). Larger farms may face greater economic risks in the event of disease outbreaks, and to protect their business, farmers may be more inclined to rely on higher AMU. In addition, breaks in biosecurity may happen more frequently in large herds where there is greater traffic of animals and people (Dhaka et al., 2023). Ultimately, labour burden and time constraints, which often occur in large settings, 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). The occurrence of methicillin-resistant *S. aureus* was more common in larger dairy herds (Schnitt and Tenhagen, 2020), suggesting an association between herd size and less responsible AMU usage, or between herd size and practices impairing animal health and increasing the need for antimicrobials (e.g., reduced milking hygiene)

4.5. Waste milk feeding

Previous research has shown that feeding milk which has been medicated with antibiotics is associated with the development of AMR bacteria, with the level of resistance of faecal pathogens increasing with higher concentrations of antibiotics in the milk (Kaneene et al., 2008). Waste milk is milk that is not suitable for human consumption, such as milk from cows with mastitis, high somatic cell counts, or cows treated with antimicrobials or other drugs (Firth et al., 2021). It has been reported that feeding waste milk to calves can lead to the emergence of antimicrobial-resistant bacteria (Maynou et al., 2017; Firth et al., 2021) and minor microbiota diversity (Penati et al., 2021). Despite less common than in previous UK surveys (Brunton et al., 2012; Higham et al., 2018), our study findings indicate that this practice is still widespread in Scotland. Indeed, in the case of two clinical disease scenarios (mastitis and metritis), around 30% of the farmers reported that they would not discard the milk after AMU administration and that the waste milk would be fed to calves. Interestingly, studies did not find any association between the intake of colostrum from cows treated with antimicrobials at dry-off and the level of AMR in calves' faecal bacteria, likely due to the low level of residues in colostrum (Jarrige et al., 2020). We did not investigate in our study whether colostrum from cows treated with antimicrobials at dry off was used to feed calves.

4.6. Dairy farmers' attitudes towards AMR and reduced farm AMU

Regarding farmers' attitudes towards AMR, in our survey we found up to 25% disagreeing with some of the statements regarding AMU reduction and AMR mitigation for animals and human health. This finding suggests that some dairy producers may still be lagging behind in acknowledging their responsibility in the fight aganist AMR. Hence, veterinarians and advisors should take into account this variation towards AMU reduction at which farmers find themselves and customize their recommendations accordingly, as a generic approach would be inadequate to accommodate the wide array of attitudes and intentions (Speksnijder and Wagenaar, 2018). We also found that, although 90% farmers agreed on the importance of decreasing AMU on UK dairy farms, only half of them thought that there is an overreliance on AMU or expressed concerns about AMR. These findings indicate that while farmers recognize the importance of reducing AMU, it is not perceived as a priority, and the consequences of AMR are not seen as an immediate risk in their daily work. In addition, we found some scepticism regarding the link between AMU in animals and AMR in humans, as previously reported in other studies (Raymond et al., 2006; Ekakoro et al., 2019; Golding et al., 2019). Reluctance to accept their responsibility to fight AMR may be a significant obstacle to enhancing AMU practices on dairy farms. Convincing farmers to modify their practices becomes challenging when they disregard the negative consequences of inappropriate AMU. Therefore, to influence farmers' AMU behaviour, an effective strategy could be to increase awareness about the potential risks of AMR for global health.

Regarding the factors influencing farmers' attitudes, we found that respondents working in large dairy herds expressed greater intentions to reduce AMU and fight AMR. This could be related to desire to proactively evade potential future limitations on AMU which could pose significant challenges for large-scale herds. Also, long-term plans of sustainability and cost-saving aspect can be particularly important for farmers working with large herds. We also found that organic farmers expressed more positive attitudes than conventional farmers in relation to AMU and AMR. This observation could be attributed to a sense of ethical responsibility among organic farmers to produce milk without any traces of antimicrobial residues, as well as a willingness to fulfil consumers' expectations regarding organic farming practices.

4.7. Study limitations

This study presents several limitations. First of all, self-selection bias can occur with voluntary participation in a survey, with overrepresentation of farmers with a particular interest in the topic or a higher educational level. In addition, social desirability bias can occur in surveys due the self-reported nature of the answers. Despite the response rate being consistent with non-random online survey, the absolute low number may limit the possibility of making inference to the general population. The absolute number of responses is is reflected in the large 95% CIs. All farmers in this study were working with milking cows, suggesting that these results may not apply to different dairy sectors, such as heifer rearing farms. In addition, some of the respondents may not have been primarily involved in AMU decision or administration of farm.

The COVID-19 pandemic greatly impacted this research in a number of ways. It affected the possibility to hold face-to-face focus groups, limiting the interaction with farmers and possibly influencing some results. In addition, we were unable promote the survey at farmers' events and to organise the number of farmers' meeting that were initially planned, as many producers were unwilling to meet online.

Although many factors influencing farmers' behavior have been identified in this and other studies, some area remain relatively unexplored. For instance, the effect of farm system (extensive grazing vs. intensive) and the level of technology implemented on farm (activity cow monitoring, automatic milking system) on farmers' AMU practices remains relatively unknown; further research in this area may provide a better indication of how to promote behavior change with specific farming systems. Also, more research is needed to better understand the relationship between farmers and veterinarians and how it can be improved with the aim to fight AMR. Future studies should therefore explore the ways to enhance leadership and communication skills in veterinarians in the field of AMU restriction, enabling them to drive behavioral changes among dairy producers.

4.8. Conclusion

This survey provides insights into the factors influencing Scottish dairy farmers' knowledge and perceptions of AMR and AMU. 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. It also highlights the need for tailored discussions with farmers regarding their own farm circumstances to give bespoke advice.

Chapter 5 – References

Ajzen, I., 1991. The Theory of Planned Behavior. Organ Behav Hum Decis Process. 50, 179–211. https://doi.org/10.1016/0749-5978(91) 90020-T

Alhaji, N.B., Aliyu, M.B., Ghali-Mohammed, I., Odetokun, I.A., 2019. Survey on antimicrobial usage in local dairy cows in North-central Nigeria: Drivers for misuse and public health threats. PLoS One 14, e0224949. https://doi.org/10.1371/journal.pone.0224949

Alliance to save our antibiotics. 2021. ANTIBIOTIC USE IN ORGANIC FARMING LOWERING USE THROUGH GOOD HUSBANDRY. https://www.saveourantibiotics.org/media/1914/20210406_antibiotic_use_in_organic_farming.pdf, n.d.

Bard, A.M., Main, D., Roe, E., Haase, A., Whay, H.R., Reyher, K.K., 2019. To change or not to change? Veterinarian and farmer perceptions of relational factors influencing the enactment of veterinary advice on dairy farms in the United Kingdom. J Dairy Sci 102, 10379–10394. https://doi.org/10.3168/jds.2019-16364

Begemann, S., Watkins, F., Van Hoyweghen, I., Vivancos, R., Christley, R., Perkins, E., 2020. The Governance of UK Dairy Antibiotic Use: Industry-Led Policy in Action. Front Vet Sci 7, 557.

Bennani, H., Mateus, A., Mays, N., Eastmure, E., Stärk, K.D.C., Häsler, B., 2020. Overview of evidence of antimicrobial use and antimicrobial resistance in the food chain. Antibiotics. https://doi.org/10.3390/antibiotics9020049

Berge, A.C.B., Champagne, S.C., Finger, R.M., Sischo, W.M., 2007. The use of bulk tank milk samples to monitor trends in antimicrobial resistance on dairy farms. Foodborne Pathog Dis 4, 397–407. https://doi.org/10.1089/fpd.2007.0009

Berge, A.C.B., Moore, D.A., Sischo, W.M., 2006. Field trial evaluating the influence of prophylactic and therapeutic antimicrobial administration on antimicrobial resistance of fecal Escherichia coli in dairy calves. Appl Environ Microbiol 72, 3872–3878. https://doi.org/10.1128/AEM.02239-05

Biesheuvel, M.M., Santman-Berends, I.M.G.A., Barkema, H.W., Ritter, C., Berezowski, J., Guelbenzu, M., Kaler, J., 2021. Understanding Farmers' Behavior and Their Decision-Making Process in the Context of Cattle Diseases: A Review of Theories and Approaches. Front Vet Sci. https://doi.org/10.3389/fvets.2021.687699

Borelli, E., Ellis, K., Tomlinson, M., Hotchkiss, E., 2022. Antimicrobial use and resistance in Scottish dairy herds: A survey of farmers' knowledge, behaviours and attitudes. BMC Vet Res. https://doi.org/10.21203/rs.3.rs-2354517/v1

British Veterinary Association (BVA). 2019. Responsible use of antimicrobials in veterinary practice 7-point plan. [WWW Document], n.d.

Brunton, L.A., Duncan, D., Coldham, N.G., Snow, L.C., Jones, J.R., 2012. A survey of antimicrobial usage on dairy farms and waste milk feeding practices in England and Wales. Vet. Rec. https://doi.org/10.1136/vr.100924

Buller, H., Adam, K., Bard, A., Bruce, A., Chan, K.W., Hinchliffe, S., Morgans, L., Rees, G., Reyher, K.K., 2020. Veterinary Diagnostic Practice and the Use of Rapid Tests in Antimicrobial Stewardship on UK Livestock Farms. Front Vet Sci 7, 569545.

C Reygaert, W., 2018a. An overview of the antimicrobial resistance mechanisms of bacteria. AIMS Microbiol 4, 482–501. https://doi.org/10.3934/microbiol.2018.3.482

Call, D.R., Davis, M.A., Sawant, A.A., 2008. Antimicrobial resistance in beef and dairy cattle production. Anim. Health Res. Rev. https://doi.org/10.1017/S1466252308001515

Castro-Sánchez, E., Drumright, L.N., Gharbi, M., Farrell, S., Holmes, A.H., 2016. Mapping antimicrobial stewardship in undergraduate medical, dental, pharmacy, nursing and veterinary education in the United Kingdom. PLoS One 11, e150056.

Christaki, E., Marcou, M., Tofarides, A., 2020. Antimicrobial Resistance in Bacteria: Mechanisms, Evolution, and Persistence. J Mol Evol. https://doi.org/10.1007/s00239-019-09914-3

Constable, P.D., 2009. Treatment of Calf Diarrhea: Antimicrobial and Ancillary Treatments. Veterinary Clinics of North America - Food Animal Practice. https://doi.org/10.1016/j.cvfa.2008.10.012

Courtenay, M., Castro-Sanchez, E., Fitzpatrick, M., Gallagher, R., Lim, R., Morris, G., 2019. Tackling antimicrobial resistance 2019–2024 – The UK's five-year national action plan. J Hosp Infect. https://doi.org/10.1016/j.jhin.2019.02.019

Dankar, I., Hassan, H., Serhan, M., 2022. Knowledge, attitudes, and perceptions of dairy farmers regarding antibiotic use: Lessons from a developing country. J Dairy Sci 105, 1519–1532. https://doi.org/10.3168/jds.2021-20951

De Jong, E., Creytens, L., De Vliegher, S., McCubbin, K.D., Baptiste, M., Leung, A.A., Speksnijder, D., Dufour, S., Middleton, J.R., Ruegg, P.L., Lam, T.J.G.M., Kelton, D.F., McDougall, S., Godden, S.M., Lago, A., Rajala-Schultz, P.J., Orsel, K., Krömker, V., Kastelic, J.P., Barkema, H.W., 2023. Selective treatment of nonsevere clinical mastitis does not adversely affect cure, somatic cell count, milk yield, recurrence, or culling: A systematic review and meta-analysis. J Dairy Sci 106, 1267–1286.

Department of Health, 2019. Tackling antimicrobial resistance 2019–2024 The UK's five-year national action plan. London. https://assets.publishing.service.gov.uk/media/6261392d8fa8f523bf22ab9e/UK_AMR_5_year_national_action_plan.pdf

Dhaka, P., Chantziaras, I., Vijay, D., Bedi, J.S., Makovska, I., Biebaut, E., Dewulf, J., 2023. Can Improved Farm Biosecurity Reduce the Need for Antimicrobials in Food Animals? A Scoping Review. Antibiotics 12, 893. https://doi.org/10.3390/antibiotics12050893

Doidge, C., Hudson, C.D., Burgess, R., Lovatt, F., Kaler, J., 2020. Antimicrobial use practices and opinions of beef farmers in England and Wales. Vet. Rec. 187, e119. https://doi.org/10.1136/vr.105878

Downing, E., n.d. UK Dairy Industry-Current issues and challenges Inside: 1. Current UK Dairy Industry trends 2. Support measures 3. Industry-led work.

Doyle, E., Heller, J., Norris, J.M., 2022. Factors influencing dairy cattle farmer use of antimicrobials on farms in New South Wales, Australia. Aust Vet J 100, 587–595. https://doi.org/10.1111/avj.13209

Dyck - Hoffmann, V.A., n.d. European Commission, 2011. Action plan against the rising threats from Antimicrobial Resistance. Brussels.

Ekakoro, J.E., Caldwell, M., Strand, E.B., Okafor, C.C., 2019. Drivers, alternatives, knowledge, and perceptions towards antimicrobial use among Tennessee beef cattle producers: A qualitative study. BMC Vet Res 15, 16. https://doi.org/10.1186/s12917-018-1731-6

European Medicine Agency (EMA). 2020. Categorisation of antibiotics used in animals promotes responsible use to protect public and animal health, n.d.

Falkenberg, U., Kromer, V., Heuwieser, W., Fischer-Tenhagen, C., 2019. Survey on routines in udder health management and therapy of mastitis on German dairy farms. Milchwissenschaft - Milk Sci Int. 71, 11–15.

FAO and VMD. 2022. Tackling antimicrobial use and resistance in food-producing animals – Lessons learned in the United Kingdom. Rome. https://doi.org/10.4060/cc0927enKINGDOM, n.d.

Farm Advisory Service, 2022. Milk Manager NEWS. https://www.fas.scot/downloads/milk-manager-news-march-2022/. Accessed 02 Dec 2022.

Farrell, S., Benson, T., McKernan, C., Regan, Á., Burrell, A.M.G., Dean, M., 2023. Factors influencing dairy farmers' antibiotic use: An application of the COM-B model. J Dairy Sci. https://doi.org/10.3168/jds.2022-22263

Firth, C.L., Kremer, K., Werner, T., Käsbohrer, A., 2021. The effects of feeding waste milk containing antimicrobial residues on dairy calf health. Pathogens. https://doi.org/10.3390/pathogens10020112

Fischer, K., Sjöström, K., Stiernström, A., Emanuelson, U., 2019. Dairy farmers' perspectives on antibiotic use: A qualitative study. J Dairy Sci 102, 2724–2737. https://doi.org/10.3168/jds.2018-15015

Founou, L.L., Founou, R.C., Essack, S.Y., 2016. Antibiotic resistance in the food chain: A developing country-perspective. Front Microbiol. https://doi.org/10.3389/fmicb.2016.01881

Friedman, D.B., Kanwat, C.P., Headrick, M.L., Patterson, N.J., Neely, J.C., Smith, L.U., 2007. Importance of prudent antibiotic use on dairy farms in South Carolina: A pilot project on farmers' knowledge, attitudes and practices. Zoonoses Public Health 54, 366–375. https://doi.org/10.1111/j.1863-2378.2007.01077.x.

Fujiwara, M., Haskell, M.J., Macrae, A.I., Rutherford, K.M.D., 2018. Survey of dry cow management on UK commercial dairy farms. Veterinary Record. https://doi.org/10.1136/vr.104755

Garcia, J., Pempek, J., Hengy, M., Hinds, A., Diaz-Campos, D., Habing, G., 2022. Prevalence and predictors of bacteremia in dairy calves with diarrhea. J Dairy Sci 105, 807–817. https://doi.org/10.3168/jds.2020-19819

Gerber, M., Dürr, S., Bodmer, M., 2020. Decision-Making of Swiss Farmers and the Role of the Veterinarian in Reducing Antimicrobial Use on Dairy Farms. Front Vet Sci 7, 565.

Golding, S.E., Ogden, J., Higgins, H.M., 2019. Shared goals, different barriers: A qualitative study of UK veterinarians' and farmers' beliefs about antimicrobial resistance and stewardship. Front Vet Sci 6, 132. https://doi.org/10.3389/fvets.2019.00132

Gosselin, V.B., Bodmer, M., Schüpbach-Regula, G., Steiner, A., Meylan, M., 2022. Survey on the disposal of waste milk containing antimicrobial residues on Swiss dairy farms. J Dairy Sci 105, 1242–1254.

Gröndal, H., Blanco-Penedo, I., Fall, N., Sternberg-Lewerin, S., 2023. Trust, agreements, and occasional breakdowns: Veterinarians' perspectives on farmer-veterinarian relationships and use of antimicrobials for Swedish dairy cattle. J Dairy Sci 106, 534–546. https://doi.org/10.3168/jds.2022-21834

Guardabassi, L., Courvalin, P., 2019. Modes of Antimicrobial Action and Mechanisms of Bacterial Resistance, in: Antimicrobial Resistance in Bacteria of Animal Origin. ASM Press, pp. 1–18. https://doi.org/10.1128/9781555817534.ch1

Habing, G., Djordjevic, C., Schuenemann, G.M., Lakritz, J., 2016. Understanding antimicrobial stewardship: Disease severity treatment thresholds and antimicrobial alternatives among organic and conventional calf producers. Prev Vet Med 130, 77–85. https://doi.org/10.1016/j.prevetmed.2016.06.004

Hawkins, O., Scott, A.M., Montgomery, A., Nicholas, B., Mullan, J., van Oijen, A., Degeling, C., 2022. Comparing public attitudes, knowledge, beliefs and behaviours towards antibiotics and antimicrobial resistance in Australia, United Kingdom, and Sweden (2010-2021): A systematic review, meta-analysis, and comparative policy analysis. PLoS One 17, e0261917.

Helliwell, R., Morris, C., Raman, S., 2019. Can resistant infections be perceptible in UK dairy farming? Palgrave Commun 5, 12. https://doi.org/10.1057/s41599-019-0220-2

Higgins, H.M., Golding, S.E., Mouncey, J., Nanjiani, I., Cook, A.J.C., 2017. Understanding veterinarians' prescribing decisions on antibiotic dry cow therapy. J Dairy Sci 100, 2909–2916. https://doi.org/10.3168/jds.2016-11923

Higham, L.E., Deakin, A., Tivey, E., Porteus, V., Ridgway, S., Rayner, A.C., 2018. A survey of dairy cow farmers in the United Kingdom: Knowledge, attitudes and practices surrounding antimicrobial use and resistance. Vet. Rec. 183, 746. https://doi.org/10.1136/vr.104986

Humphry, R.W., Henry, M.K., Reeves, A., Correia-Gomes, C., Innocent, G.T., Smith, R., Mason, C.S., Gunn, G.J., Tongue, S.C., 2021. Estimating antimicrobial usage based on sales to beef and dairy farms from UK veterinary practices. Veterinary Record 189, no. https://doi.org/10.1002/vetr.28

Hyde, R.M., Remnant, J.G., Bradley, A.J., Breen, J.E., Hudson, C.D., Davies, P.L., Clarke, T., Critchell, Y., Hylands, M., Linton, E., Wood, E., Green, M.J., 2017. Quantitative analysis of antimicrobial use on British dairy farms. Vet. Rec. 181, 683.

Jarrige, N., Cazeau, G., Bosquet, G., Bastien, J., Benoit, F., Gay, E., 2020. Effects of antimicrobial exposure on the antimicrobial resistance of Escherichia coli in the digestive flora of dairy calves. Prev Vet Med 185, 105177.

Johnson, Sannes, Croy, Johnston, Clabots, Kuskowski, Belongia, 2007. Drug-Resistant E. coli from Humans and Poultry. Emerg. Infect. Dis. 13, 838–846.

Jones, P.J., Marier, E.A., Tranter, R.B., Wu, G., Watson, E., Teale, C.J., 2015. Factors affecting dairy farmers' attitudes towards antimicrobial medicine usage in cattle in England and Wales. Prev Vet Med 121, 30–40. https://doi.org/10.1016/j.prevetmed.2015.05.010

Kaneene, J.B., Warnick, L.D., Bolin, C.A., Erskine, R.J., May, K., Miller, R.A., 2008. Changes in tetracycline susceptibility of enteric bacteria following switching to nonmedicated milk replacer for dairy calves. J Clin Microbiol 46, 1968–1977. https://doi.org/10.1128/JCM.00169-08

Kayitsinga, J., Schewe, R.L., Contreras, G.A., Erskine, R.J., 2017. Antimicrobial treatment of clinical mastitis in the eastern United States: The influence of dairy farmers' mastitis management and treatment behavior and attitudes. J Dairy Sci 100, 1388–1407. https://doi.org/10.3168/jds.2016-11708

Kramer, T., Jansen, L.E., Lipman, L.J.A., Smit, L.A.M., Heederik, D.J.J., Dorado-García, A., 2017. Farmers' knowledge and expectations of antimicrobial use and resistance are strongly related to usage in Dutch livestock sectors. Prev Vet Med 147, 142–148. https://doi.org/10.1016/j.prevetmed.2017.08.023

Krömker, V., Leimbach, S., 2017. Mastitis treatment—Reduction in antibiotic usage in dairy cows. Reprod. Domest. Anim. https://doi.org/10.1111/rda.13032

Kuhnen, S., de Mello, D.F.M., Honorato, L.A., Piccinin, I.N., Martins, J., Bernardes, P.A., Pinheiro Machado Filho, L.C., 2021. Identification and antimicrobial susceptibility of milk pathogen isolated from dairy production systems. Prev Vet Med 194. https://doi.org/10.1016/j.prevetmed.2021.105451

Landers, T.F., Cohen, B., Wittum, T.E., Larson, E.L., n.d. A Review of Antibiotic Use in Food Animals: Perspective, Policy, and Potential.

Lee, J.H., 2003. Methicillin (Oxacillin)-Resistant Staphylococcus aureus Strains Isolated from Major Food Animals and their Potential Transmission to Humans. Appl Environ Microbiol 69, 6489–6494. https://doi.org/10.1128/AEM.69.11.6489-6494.2003

Llanos-Soto, S.G., Vezeau, N., Wemette, M., Bulut, E., Greiner Safi, A., Moroni, P., Shapiro, M.A., Ivanek, R., 2021. Survey of perceptions and attitudes of an international group of veterinarians regarding antibiotic use and resistance on dairy cattle farms. Prev Vet Med 188, 105253. https://doi.org/10.1016/j.prevetmed.2020.105253

Loeb, J., 2021. Antibiotics breach is “deeply concerning.” Vet Rec. https://doi.org/10.1002/vetr.254

Marshall, B.M., Levy, S.B., 2011. Food animals and antimicrobials: Impacts on human health. Clin Microbiol Rev. https://doi.org/10.1128/CMR.00002-11

Maynou, G., Bach, A., Terré, M., 2017. Feeding of waste milk to Holstein calves affects antimicrobial resistance of Escherichia coli and Pasteurella multocida isolated from fecal and nasal swabs. J Dairy Sci 100, 2682–2694. https://doi.org/10.3168/jds.2016-11891

McCubbin, K.D., de Jong, E., Lam, T.J.G.M., Kelton, D.F., Middleton, J.R., McDougall, S., De Vliegher, S., Godden, S., Rajala-Schultz, P.J., Rowe, S., Speksnijder, D.C., Kastelic, J.P., Barkema, H.W., 2022. Invited review: Selective use of antimicrobials in dairy cattle at drying-off. J Dairy Sci. https://doi.org/10.3168/jds.2021-21455

McDougall, S., Compton, C.W.R., Botha, N., 2017. Factors influencing antimicrobial prescribing by veterinarians and usage by dairy farmers in New Zealand. N Z Vet J 65, 84–92.

McDougall, S., Penry, J., Dymock, D. 2021. Antimicrobial susceptibilities in dairy herds that differ in dry cow therapy usage. J Dairy Sci. 104:9142-9163. https://doi.org/10.3168/jds.2020-19925

McKernan, C., Benson, T., Farrell, S., Dean, M., 2021. Antimicrobial use in agriculture: Critical review of the factors influencing behaviour. JAC Antimicrob Resist 3, dlab178. https://doi.org/doi: 10.1093/jacamr/dlab178

McLaughlin, D., Bradley, A., Dottorini, T., Giebel, K., Leach, K., Hyde, R., Green, M., 2022. Identifying associations between management practices and antimicrobial resistances of sentinel bacteria recovered from bulk tank milk on dairy farms. Prev Vet Med 204. https://doi.org/10.1016/j.prevetmed.2022.105666

Mills, H.L., Turner, A., Morgans, L., Massey, J., Schubert, H., Rees, G., Barrett, D., Dowsey, A., Reyher, K.K., 2018. Evaluation of metrics for benchmarking antimicrobial use in the UK dairy industry. Veterinary Record. https://doi.org/10.1136/vr.104701

Morgans, L.C., Bolt, S., Bruno-McClung, E., van Dijk, L., Escobar, M.P., Buller, H.J., Main, D.C.J., Reyher, K.K., 2021. A participatory, farmer-led approach to changing practices around antimicrobial use on UK farms. J Dairy Sci 104, 2212–2230. https://doi.org/10.3168/jds.2020-18874

Nobrega, D.B., De Buck, J., Barkema, H.W., 2018. Antimicrobial resistance in non-aureus staphylococci isolated from milk is associated with systemic but not intramammary administration of antimicrobials in dairy cattle. J Dairy Sci 101, 7425–7436. https://doi.org/10.3168/jds.2018-14540

O'Neill J, 2016. O'Neil, J. 2016. Tackling drug-resistant infections globally: final report and recommendations, in: Ro, A. (Ed.), Resistance. London.

Orpin P, 2017. What can we learn from farmers experiences and attitudes to Selective Dry Cow Therapy? Cattle Pract. 25, 130–139.

Ozdikmenli Tepeli, S., 2023. A Survey of knowledge, attitude, and practices surrounding antimicrobial use by family dairy farmers to mastitis control. Prev Vet Med 214. https://doi.org/10.1016/j.prevetmed.2023.105904

Ozturk, Y., Celik, S., Sahin, E., Acik, M.N., Cetinkaya, B., 2019. Assessment of farmers' knowledge, attitudes and practices on antibiotics and antimicrobial resistance. Animals 9, 653. https://doi.org/10.3390/ani9090653

Penati, M., Sala, G., Biscarini, F., Boccardo, A., Bronzo, V., Castiglioni, B., Cremonesi, P., Moroni, P., Pravettoni, D., Addis, M.F., 2021. Feeding Pre-weaned Calves With Waste Milk Containing Antibiotic Residues Is Related to a Higher Incidence of Diarrhea and Alterations in the Fecal Microbiota. Front Vet Sci 8. https://doi.org/10.3389/fvets.2021.650150

Poizat, A., Bonnet-Beaugrand, F., Rault, A., Fourichon, C., Bareille, N., 2017. Antibiotic use by farmers to control mastitis as influenced by health advice and dairy farming systems. Prev Vet Med 146, 61–72. https://doi.org/10.1016/j.prevetmed.2017.07.016

Raymond, M.J., Wohrle, R.D., Call, D.R., 2006. Assessment and promotion of Judicious antibiotic use on dairy farms in Washington State. J Dairy Sci 89, 3228–3240.

Red Tractor Assurances for Farms. Dairy Standards. 2021. https://redtractorassurance.org.uk/wp-content/uploads/2021/08/RTStandardsV5_Dairy_SINGLES.pdf. Accessed 02 Dec 2022, n.d.

Rees, G.M., Barrett, D.C., Sánchez-Vizcaíno, F., Reyher, K.K., 2021. Measuring antimicrobial use on dairy farms: A method comparison cohort study. J Dairy Sci 104, 4715–4726. https://doi.org/10.3168/jds.2020-18690

REGULATION (EC) No 1831/2003 of the European Parliament and of the Council on additives for use in animal nutrition. 2003. Official Journal of the European Union. L268/29, n.d.

Richens, I.F., Houdmont, J., Wapenaar, W., Shortall, O., Kaler, J., O'Connor, H., Brennan, M.L., 2018. Application of multiple behaviour change models to identify determinants of farmers' biosecurity attitudes and behaviours. Prev Vet Med 155, 61–74.

Ritter, C., Adams, C.L., Kelton, D.F., Barkema, H.W., 2019. Factors associated with dairy farmers' satisfaction and preparedness to adopt recommendations after veterinary herd health visits. J Dairy Sci 102, 4280–4293. https://doi.org/10.3168/jds.2018-15825

Ritter, C., Jansen, J., Roche, S., Kelton, D.F., Adams, C.L., Orsel, K., Erskine, R.J., Benedictus, G., Lam, T.J.G.M., Barkema, H.W., 2017. Invited review: Determinants of farmers' adoption of management-based strategies for infectious disease prevention and control. J Dairy Sci. https://doi.org/10.3168/jds.2016-11977

Ritter, C., Kwong, G.P.S., Wolf, R., Pickel, C., Slomp, M., Flaig, J., Mason, S., Adams, C.L., Kelton, D.F., Jansen, J., de Buck, J., Barkema, H.W., 2015. Factors associated with participation of Alberta dairy farmers in a voluntary, management-based Johne's disease control program. J Dairy Sci 98, 7831–7845. https://doi.org/10.3168/jds.2015-9789

Ruegg, P.L., 2021. What Is Success? A Narrative Review of Research Evaluating Outcomes of Antibiotics Used for Treatment of Clinical Mastitis. Front Vet Sci. https://doi.org/10.3389/fvets.2021.639641

RUMA (2017). Targets Task Force Report 2017. https://www.nfuonline.com/archive?treeid=101251 Accessed 28 Jan 2023, n.d.

RUMA Alliance (Responsible Use of Medicines in Agriculture), 2015. Responsible use of antimicrobials in cattle production. https://www.ruma.org.uk/wp-content/uploads/2015/07/RUMA_antimicrobial_long_cattle_revised_2015.pdf. Accessed 02 Dec 2022.

RUMA Alliance (Responsible Use of Medicines in Agriculture). 2020. Targets Task Force Report 2021-2024. https://ruma.org.uk/wp-content/uploads/2022/07/RUMA-REPORT-021220.pdf Accessed 02 Dec 2022.

Saini, V., McClure, J.T., Léger, D., Keefe, G.P., Scholl, D.T., Morck, D.W., Barkema, H.W., 2012. Antimicrobial resistance profiles of common mastitis pathogens on Canadian dairy farms. J Dairy Sci 95, 4319–4332. https://doi.org/10.3168/jds.2012-5373

Scherpenzeel, C.G.M., den Uijl, I.E.M., van Schaik, G., Riekerink, R.G.M.O., Hogeveen, H., Lam, T.J.G.M., 2016. Effect of different scenarios for selective dry-cow therapy on udder health, antimicrobial usage, and economics. J Dairy Sci 99, 3753–3764. https://doi.org/10.3168/jds.2015-9963

Schnitt, A., Tenhagen, B.A., 2020. Risk Factors for the Occurrence of Methicillin-Resistant Staphylococcus aureus in Dairy Herds: An Update. Foodborne Pathog Dis. https://doi.org/10.1089/fpd.2019.2638

Schwendner, A.A., Lam, T.J.G.M., Bodmer, M., Cousin, M.E., Schüpbach-Regula, G., van den Borne, B.H.P., 2020. Knowledge, attitude and practices of Swiss dairy farmers towards intramammary antimicrobial use and antimicrobial resistance: A latent class analysis. Prev Vet Med 179, 105023.

Scottish government. 2016. Economic Report on Scottish Agriculture**.** https://www.gov.scot/publications/economic-report-scottish-agriculture-2016/pages/34/ Accessed 02 Dec 2022.

Sharma, C., Rokana, N., Chandra, M., Singh, B.P., Gulhane, R.D., Gill, J.P.S., Ray, P., Puniya, A.K., Panwar, H., 2018. Antimicrobial resistance: Its surveillance, impact, and alternative management strategies in dairy animals. Front Vet Sci. https://doi.org/10.3389/fvets.2017.00237

Shortall, O.K., Lorenzo-Arribas, A., 2022. Dairy farmer practices and attitudes relating to pasture-based and indoor production systems in Scotland. PLoS One 17, e0262268. https://doi.org/10.1371/journal.pone.0262268

Skjølstrup, N.K., Nielsen, L.R., Jensen, C.S., Lastein, D.B., 2021. Veterinary Herd Health Consultancy and Antimicrobial Use in Dairy Herds. Front Vet Sci. https://doi.org/10.3389/fvets.2020.547975

Speksnijder, D.C., Jaarsma, D.A.C., Verheij, T.J.M., Wagenaar, J.A., 2015. Attitudes and perceptions of Dutch veterinarians on their role in the reduction of antimicrobial use in farm animals. Prev Vet Med 121, 365–373. https://doi.org/10.1016/j.prevetmed.2015.08.014

Speksnijder, D.C., Wagenaar, J.A., 2018. Reducing antimicrobial use in farm animals: How to support behavioral change of veterinarians and farmers. Anim. Front. 8, 4–9. https://doi.org/10.1093/af/vfy006

Statuatory Instruments. The Veterinary Medicine Regulations No. 2033. 2013. https://www.legislation.gov.uk/uksi/2013/2033/made. Accessed 02 Dec 2022, n.d.

Swinkels, J.M., Hilkens, A., Zoche-Golob, V., Krömker, V., Buddiger, M., Jansen, J., Lam, T.J.G.M., 2015. Social influences on the duration of antibiotic treatment of clinical mastitis in dairy cows. J Dairy Sci 98, 2369–2380. https://doi.org/10.3168/jds.2014-8488

Tang, K.L., Caffrey, N.P., Nóbrega, D.B., Cork, S.C., Ronksley, P.E., Barkema, H.W., Polachek, A.J., Ganshorn, H., Sharma, N., Kellner, J.D., Ghali, W.A., 2017. Restricting the use of antibiotics in food-producing animals and its associations with antibiotic resistance in food-producing animals and human beings: a systematic review and meta-analysis. Lancet Planet Health 1, e316–e327. https://doi.org/10.1016/S2542-5196(17)30141-9

Tijs, S.H.W., Holstege, M.M.C., Scherpenzeel, C.G.M., Santman-Berends, I.M.G.A., Velthuis, A.G.J., Lam, T.J.G.M., 2022. Effect of selective dry cow treatment on udder health and antimicrobial usage on Dutch dairy farms. J Dairy Sci 105, 5381–5392. https://doi.org/10.3168/jds.2021-21026

Uberoi, E., 2021. UK dairy industry statistics Summary 1 UK Dairy Herd and producers 2 Production 3 International Trade 4 Consumption 5 Farm-gate Prices.

Uyama, T., Kelton, D.F., Morrison, E.I., De Jong, E., Mccubbin, K.D., Barkema, H.W., Dufour, S., Sanchez, J., Heider, L.C., Leblanc, S.J., Winder, C.B., Mcclure, J.T., Renaud, D.L., 2022. Cross-sectional study of antimicrobial use and treatment decision for preweaning Canadian dairy calves 3, 72–77. https://doi.org/10.3168/jdsc.2021-0161

Van Boeckel, T.P., Pires, J., Silvester, R., Zhao, C., Song, J., Criscuolo, N.G., Gilbert, M., Bonhoeffer, S., Laxminarayan, R., 2019. Global trends in antimicrobial resistance in animals in low- And middle-income countries. Science (1979) 365. https://doi.org/10.1126/science.aaw1944

van Bunnik, B.A.D., Woolhouse, M.E.J., 2017. Modelling the impact of curtailing antibiotic usage in food animals on antibiotic resistance in humans. R Soc Open Sci 4. https://doi.org/10.1098/rsos.161067

Velasova, M., Damaso, A., Prakashbabu, B.C., Gibbons, J., Wheelhouse, N., Longbottom, D., Van Winden, S., Green, M., Guitian, J., 2017. Herd-level prevalence of selected endemic infectious diseases of dairy cows in Great Britain. J Dairy Sci 100, 9215–9233. https://doi.org/10.3168/jds.2016-11863

Veterinary Medicine Directorate. UK Veterinary Antibiotic Resistance and Sales Surveillance Report. UK-VARSS 2020. 2021. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1072796/03.05.22_VARSS_Main_Report__Final_Accessible_version__3_.pdf. Accessed 02 Dec 2022, n.d.

Veterinary Medicines Directorate (VMD), 2019. UK One Health Report - Joint report on antibiotic use and antibiotic resistance, 2013–2017.

Wemette, M., Greiner Safi, A., Wolverton, A.K., Beauvais, W., Shapiro, M., Moroni, P., Welcome, F.L., Ivanek, R., 2021. Public perceptions of antibiotic use on dairy farms in the United States. J Dairy Sci 104, 2807–2821. https://doi.org/10.3168/jds.2019-17673

Wepking, C., Badgley, B., Barrett, J.E., Knowlton, K.F., Lucas, J.M., Minick, K.J., Ray, P.P., Shawver, S.E., Strickland, M.S., 2019. Prolonged exposure to manure from livestock-administered antibiotics decreases ecosystem carbon-use efficiency and alters nitrogen cycling. Ecol Lett. https://doi.org/10.1111/ele.13390

White, A., Hughes, J.M., 2019. Critical Importance of a One Health Approach to Antimicrobial Resistance. Ecohealth 16, 404–409. https://doi.org/10.1007/s10393-019-01415-5

WHO (World Health Organisation), 2005. Critically important antibacterial agents for human medicine for risk management strategies of non-human use. Canberra., n.d.

WHO (World Health Organisation), 2018. Critically important antimicrobials for human medicine – 6th rev. Utrecht., n.d.

Wolak, I., Czatzkowska, M., Harnisz, M., Jastrzębski, J.P., Paukszto, Ł., Rusanowska, P., Felis, E., Korzeniewska, E., 2022. Metagenomic Analysis of the Long-Term Synergistic Effects of Antibiotics on the Anaerobic Digestion of Cattle Manure. Energies (Basel) 15. https://doi.org/10.3390/en15051920

World Health Organisation (WHO), 2021. Antimicrobial resistance [WWW Document]. URL https://www.who.int/news-room/fact-sheets/detail/antimicrobial-resistance. Accessed 02 Dec 2022

World Organization for Animal Health. 2021. OIE LIST OF ANTIMICROBIAL AGENTS OF VETERINARY IMPORTANCE, n.d.

Zhang, X.Y., Ding, L.J., Fan, M.Z., 2009. Resistance patterns and detection of aac(3)-IV gene in apramycin-resistant Escherichia coli isolated from farm animals and farm workers in northeastern of China. Res Vet Sci 87, 449–454. https://doi.org/10.1016/j.rvsc.20

Appendix I – Focus group and workshop questions

Focus group questions – open discussion:

1. How do you feel about antimicrobial resistance?

2. Do you think there is too much reliance on antimicrobial usage on dairy farms?

3. Do you think some antimicrobials work less effectively than in the past?

4. Which advantages and disadvantages are associated with reducing antimicrobial usage?

5. Do you think your farm antimicrobial usage has changed in recent years?

6. Do you expect your antimicrobial usage to change over the next 5 years?

Workshop questions pools and answer choices:

1. How concerned are you about antimicrobial resistance on dairy farms?

   - Very concerned
   - Concerned to some extent
   - I don't think about it much either way
   - Not concerned at all

2. Which is your main source of information regarding correct antimicrobial usage?

   - Veterinarians
   - Websites
   - Farming articles
   - Guidance from milk buyer
   - Other farmers
   - Not sure/other

3. Do you think antimicrobial usage has changed on dairy farms over the last few years?

- It has increased
- It is about the same
- It has decreased
- Not sure

4. Which of the following diseases is the main reason for antimicrobial usage on your farm?

- Mastitis
- Calf pneumonia/diarrhea
- Lameness
- Metritis/post-calving disease
- Dry cow therapy
- Other

5. Which is your most frequently used antimicrobial?

- Beta-lactams/Streptomycin (Pen-Strep®)
- Oxytetracycline (Alamycin®)
- Tylosin (Tylan®)
- Ceftiofur (Naxcel®)
- Other

6. Do you think it is possible to reduce antimicrobial use on dairy farms?

- Yes, easily
- Yes, possible but with some barriers
- No, too difficult
- Not sure

7. Which one of the following would be the main barrier in reducing antimicrobial use on your dairy farm?

- Limited knowledge/training
- Limited time/labour
- Limited finances
- Lack of staff compliance
- Not sure/other

8. Which of the following would be the main advantage in reducing antimicrobial use on dairy farms?

- Reduced antimicrobial cost
- Reduced antimicrobial resistance Increased consumer confidence
- Increased milk safety
- Not sure

9. Which of the following would be the main disadvantage in reducing antimicrobial use on dairy farms?

- Reduced animal welfare
- Reduced milk production
- Increased disease/mortality
- Time consuming/ increased labour
- Not sure

Appendix II – Survey

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)
   - Analgesic (reduce pain)
   - Anti-inflammatory (reduce inflammation)
   - Antipyretic (reduce animal's temperature)
   - Anti-bacterial (kill or inhibit bacteria causing the infection)
   - 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
   - No

5.a. If yes, how familiar are you with the guidelines?
   - Not familiar at all
   - Somewhat familiar
   - 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...)
   - Never
   - Once
   - More than once
   - 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...)?
   - Never
   - Once

- More than once
- Once every week or more

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

- Never
- Sometimes
- Most of the time
- Always

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

- Yes
- No

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

- Annually
- Every six months
- Monthly
- 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

- Not used
- Used with low confidence
- Used with medium confidence
- 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

- Not important
- Somewhat important
- Very important

12. Which is your most frequently used antibiotic?

- Penicillin/Amoxycillin
- Oxytetracycline
- Tylosin
- Ceftiofur
- 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

- Mastitis
- Calf pneumonia
- Calf scour
- Lameness
- Post-partum diseases
- Dry cow therapy

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

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

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

- Yes
- No, but I am considering developing it in the future
- 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
- Previous treatment unsuccessful
- Several animals involved
- Animal welfare
- Others

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

- Cost
- Delay in treating animals
- Vet visit means additional work
- I have enough experience
- 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

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

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

- Never
- Occasionally
- Regularly

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

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

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

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

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

- Less
- Same
- More

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

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

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

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

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

- Less
- Same
- 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

- No influence
- Some influence
- 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

- Not concerning
- Somewhat concerning
- 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?

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

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

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

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

- Throw it away

- Feed to all calves
- Feed to some calves but not replacement heifers
- Other

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

26.a. What would you do first?

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

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

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

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

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

27.a. What would you do first?

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

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

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

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

- Yes
- No
- 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?

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

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

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

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

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

- Other

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

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

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

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

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

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

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

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

36. Some antibiotics work less effectively than in the past

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

37. Farmers require more training on antibiotic usage

- Strongly agree
- Agree

- Neither agree nor disagree
- Disagree
- Strongly disagree

38. Farm biosecurity and vaccination can reduce antibiotic usage

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

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

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

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

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

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

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

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

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- 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

- Strongly agree

- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

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

- Strongly agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly disagree

45. What is your age?

- 18-35
- 36-50
- More than 51
- Prefer not to say

46. What is your sex?

- Male
- Female
- Prefer not to say

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

- Less than 5
- 6-20
- 21-40
- More than 41

48. What is your highest level of education?

- High school
- Agricultural college
- University
- Other

49. Is your dairy farm:

- Conventional
- Organic

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

- Milking/dry cows

- Replacement heifers (weaned)
- Calves unweaned (male and female)
- Dairy bulls
- Other

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

- No
- BVD
- Johnes
- Lepto
- IBR
- Other

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

- Yes
- No

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

- No
- Sheep
- Beef
- Other

54. What is your role in the enterprise?

- Owner
- Dairy manager
- Other

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

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

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

Appendix III – Survey PDF (Jisc)

Appendix III – Survey PDF (Jisc)

Jisc Online surveys

Knowledge, behaviours and attitudes of Scottish dairy farmers towards antimicrobial use (copy) 19.04 (copy) (copy)

Showing 0 of 0 responses

Showing **all** responses

Showing **all** questions

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

Yes	0
No	0

2 What does "Antibiotic resistance" mean to you in your own words?

No responses

3 In your opinion, are antibiotics effective against the following pathogenic organisms?

3.1 Viruses

3.1.a Viruses

Not Effective at all	0
Somewhat Effective	0
Very effective	0
Don't know	0

3.2 Bacteria

3.2.a Bacteria

Appendix III – Survey PDF (Jisc)

Not Effective at all	0
Somewhat Effective	0
Very effective	0
Don't know	0

3.3 Parasites

3.3.a Parasites

Not Effective at all	0
Somewhat Effective	0
Very effective	0
Don't know	0

4 What effects do antibiotics have? (tick all that apply)

Analgesic (reduce pain)	0
Anti-inflammatory (reduce inflammation)	0
Antipyretic (reduce the animal's temperature)	0
Anti-bacterial (kill or inhibit bacteria causing infection)	0
Other	0

Multi answer: Percentage of respondents who selected each answer option (e.g. 100% would represent that all this question's respondents chose that option)

4.a If you selected Other, please specify:

No responses

5 Have you ever heard of the RUMA (Responsible Use of Medicine in Agriculture) guidelines for the

Appendix III – Survey PDF (Jisc)

responsible use of antibiotics in cattle production?

Yes	0
No	0

5.a How familiar are you with the guidelines?

Not familiar at all	0
Somewhat familiar	0
Very familiar	0
Completely familiar	0

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...)

Never	0
Once	0
More than once	0
Once every week or more	0

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...)?

Never	0
Once	0
More than once	0
Once every week or more	0

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

Appendix III – Survey PDF (Jisc)

Never	0
Sometimes	0
Most of the time	0
Always	0

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

Yes	0
No	0

9.a How often do you speak about it approximately?

Annually	0
Every 6 months	0
Monthly	0
At every visit	0

10 Have you ever sought advice on antibiotic use from any of the following sources and how confident are you in the information you received? Tick if the followiong sources are used and the level of confidence on them

10.1 Farming articles

10.1.a Farming articles

Not used	0
Used with low confidence	0
Used with medium confidence	0
Used with high confidence	0

10.2 Other farmers

10.2.a Other farmers

Not used	0
Used with low confidence	0
Used with medium confidence	0
Used with high confidence	0

10.3 Websites

10.3.a Websites

Not used	0
Used with low confidence	0
Used with medium confidence	0
Used with high confidence	0

10.4 Guidance from milk purchasers

10.4.a Guidance from milk purchasers

Not used	0
Used with low confidence	0
Used with medium confidence	0
Used with high confidence	0

10.5 Veterinarian

10.5.a Veterinarian

Not used	0
Used with low confidence	0
Used with medium confidence	0
Used with high confidence	0

10.6 Herd health plan

10.6.a Herd health plan

Not used	0
Used with low confidence	0
Used with medium confidence	0
Used with high confidence	0

10.a Please, specify any other source of information that you may use

No responses

11 How important to you is the opinion of the following people around antibiotic reduction? Tick the degree of importance for each person/people

11.1 Your vet

11.1.a Your vet

Not important	0
Somewhat important	0
Very important	0

11.2 Other farmers

11.2.a Other farmers

Not important	0
Somewhat important	0
Very important	0

11.3 Retailer

11.3.a Retailer

Not important	0
Somewhat important	0
Very important	0

11.4 Consumers

11.4.a Consumers

Not important	0
Somewhat important	0
Very important	0

11.5 Feed adviser

11.5.a Feed adviser

Not important	0
Somewhat important	0
Very important	0

11.6 Employees

Appendix III – Survey PDF (Jisc)

11.6.a Employees

Not important	0
Somewhat important	0
Very important	0

11.7 Your family

11.7.a Your family

Not important	0
Somewhat important	0
Very important	0

11.a Please, specify any other person/people whose opinion may be important for you

No responses

12 Which is your most frequently used antibiotic?

Penicillin/Amoxycillin	0
Oxytetracycline	0
Tylosin	0
Ceftiofur	0
Other	0

12.a If you selected Other, please specify:

No responses

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

Appendix III – Survey PDF (Jisc)

13.1 Mastitis

13.1.a Mastitis - Write 1 to 6

No responses

13.2 Calf pneumonia

13.2.a Calf pneumonia - Write 1 to 6

No responses

13.3 Calf scour

13.3.a Calf scour - Write 1 to 6

No responses

13.4 Lameness

13.4.a Lameness - Write 1 to 6

No responses

13.5 Metritis/post calving diseases

13.5.a Metritis/post calving diseases - Write 1 to 6

No responses

13.6 Dry cow therapy

13.6.a Dry cow therapy - Write 1 to 6

No responses

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

Yes	0
No	0

14.a Which practices do you use?

No responses

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

Yes	0
No, but I am considering developing it in the future	0
No, and I do not intend to do it	0

15.a Since when (year)?

No responses

15.b Who collaborated in the writing of the protocols? (tick all that apply)

Vet	0
Milk buyer	0
Feed adviser	0
Other	0

Multi answer: Percentage of respondents who selected each answer option (e.g. 100% would represent that all this question's respondents chose that option)

15.b.i If you selected Other, please specify:

No responses

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

Economic value of the animal	0
Previous treatment unsuccessful	0
Several animals involved	0
Other	0

16.a If you selected Other, please specify:

No responses

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

Cost	0
Delay in treating animal	0
Vet visit means additional work	0
Other	0

17.a If you selected Other, please specify:

No responses

18 Which factors do you consider important when choosing an antibiotic? Tick if the following factors are considered and the related level of importance for you

18.1 Cost

18.1.a Cost

Not considered	0
Considered with low importance	0
Considered with medium importance	0
Considered with high importance	0

18.2 Familiarity

18.2.a Familiarity

Not considered	0
Considered with low importance	0
Considered with medium importance	0
Considered with high importance	0

18.3 Withdrawal period

18.3.a Withdrawal period

Not considered	0
Considered with low importance	0
Considered with medium importance	0
Considered with high importance	0

18.4 Vet advice

18.4.a Vet advice

Not considered	0
Considered with low importance	0
Considered with medium importance	0
Considered with high importance	0

Appendix III – Survey PDF (Jisc)

18.5 Availability on farm

18.5.a Availability on farm

Not considered	0
Considered with low importance	0
Considered with medium importance	0
Considered with high importance	0

18.6 How well usually it works on my farm

18.6.a How well usually it works on my farm

Not considered	0
Considered with low importance	0
Considered with medium importance	0
Considered with high importance	0

18.a Please, specify any other factor that you may consider

No responses

19 How frequently do you send samples for culture and sensitivity before using antibiotic?

Never	0
Only occasionally	0
Regularly	0
Always	0

Appendix III – Survey PDF (Jisc)

19.a Why? (tick all that apply)

Too expensive	0
It takes time before having the results	0
I am not sure about the benefits	0
Other	0

Multi answer: Percentage of respondents who selected each answer option (e.g. 100% would represent that all this question's respondents chose that option)

19.a.i If you selected Other, please specify:

No responses

20 Do you use selective dry cow therapy in your farm?

Yes	0
No, but I am considering doing it in the future	0
No, and I do not intend to do it	0

20.a Since when (year)?

No responses

20.b In which approximate percentage of milking cows?.

No responses

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

Less	0
Same	0
More	0

21.a What are the main reasons?

No responses

21.b How difficult was it?

Very difficult	0
Somewhat difficult	0
Not difficult at all	0
I do not know	0

21.c How difficult do you think it would be to decrease the use of antibiotic on your farm?

Very difficult	0
Somewhat difficult	0
Not difficult at all	0
I do not know	0

21.d If you think it was/would be difficult, what are the main barriers (if any) to reducing antibiotic use on your farm? (tick all that apply)

I do not have enough knowledge	0
Limited finances	0
Limited facilities (e.g. isolation pens)	0
Increased labour	0
Lack of staff compliance	0
None of them	0
Other	0

Multi answer: Percentage of respondents who selected each answer option (e.g. 100% would represent that all this question's respondents chose that option)

21.d.i If you selected Other, please specify:

No responses

22 How do you expect your usage of antibiotic to change over the next 5 years?

A lot more	0
A little more	0
About the same	0
A little less	0
A lot less	0
I don't know	0

23 How much would the following factors influence your decision to reduce antibiotic use on farm? Tick the degree of influence of each factor

23.1 Reduced cost

23.1.a Reduced cost

No influence	0
Some influence	0
A lot of influence	0

23.2 Reduced animal antibiotic resistance

23.2.a Reduced animal antibiotic resistance

No influence	0
Some influence	0
A lot of influence	0

23.3 Reduced human antibiotic resistance

23.3.a Reduced human antibiotic resistance

No influence	0
Some influence	0
A lot of influence	0

23.4 Minimize the risk of antibiotic residue in milk

23.4.a Minimize the risk of antibiotic residue in milk

No influence	0
Some influence	0
A lot of influence	0

23.5 More consumer confidence

23.5.a More consumer confidence

No influence	0
Some influence	0
A lot of influence	0

23.6 Meet milk buyer standard

23.6.a Meet milk buyer standard

No influence	0
Some influence	0
A lot of influence	0

23.a Please, specifiy any other factor that may influence your decision

No responses

24 How much do the following factors concern you around reducing antibiotic use on farm? Tick the degree of concern of each factor

24.1 Increased animal disease/death

24.1.a Increased animal disease/death

Not concerning	0
Somewhat concerning	0
Very concerning	0

24.2 Decreased profitability

24.2.a Decreased profitability

Not concerning	0
Somewhat concerning	0
Very concerning	0

24.3 Decreased milk production

24.3.a Decreased milk production

Not concerning	0
Somewhat concerning	0
Very concerning	0

24.4 Reduced animal welfare

24.4.a Reduced animal welfare

Not concerning	0
Somewhat concerning	0
Very concerning	0

24.5 Increased other costs (i.e. facilities)

24.5.a Increased other costs (i.e. facilities)

Not concerning	0
Somewhat concerning	0
Very concerning	0

24.6 Time consuming

24.6.a Time consuming

Not concerning	0
Somewhat concerning	0
Very concerning	0

24.a Please, specify any other factor may concern you

No responses

25 What would you do first?

Call the vet	0
Administer intramammary antibiotic tube	0
Administer a systemic antibiotic	0
Take a milk sample for culture	0
Other	0

25.a Which systemic and/or intramammary antibiotic would you choose?

No responses

25.b What do you do with the sample?

On-farm culture	0
Send to the lab	0
Freeze and monitor if the cow respond to treatment	0
Other	0

25.b.i If you selected Other, please specify:

Appendix III – Survey PDF (Jisc)

No responses

25.c If you selected Other, please specify:

No responses

26 Where do you usually record the treatment? (tick all that apply)

I usually don't record, I remember	0
Treatment book (hard copy)	0
Mark the cow	0
Computer	0
Smartphone	0
Other	0

Multi answer: Percentage of respondents who selected each answer option (e.g. 100% would represent that all this question's respondents chose that option)

26.a If you selected Other, please specify:

No responses

27 What do you usually do with the discarded milk?

I throw it away	0
Feed all calves	0
Feed some calves but not replacement heifers	0
Feed calves after treatment of the milk (example pasteurisation)	0
Other	0

27.a If you selected Other, please specify:

No responses

Appendix III – Survey PDF (Jisc)

28 What would you do first?

Administer an antibiotic	0
Oral rehydration and /or anti-inflammatory and wait before further treatment	0
Call the vet	0
Other	0

28.a If you selected Other, please specify:

No responses

28.b Which one?

No responses

28.c Why do you wait before using antibiotic? (tick all that apply)

It's not worth treating calves	0
The disease is not severe enough	0
Just one calf is affected	0
I want to use antibiotics responsibly	0
I don't usually use antibiotics for calf scour	0
It is not advised in my written protocols	0
Other	0

Multi answer: Percentage of respondents who selected each answer option (e.g. 100% would represent that all this question's respondents chose that option)

28.c.i If you selected Other, please specify:

No responses

Appendix III – Survey PDF (Jisc)

29 What would you do to limit the spread to other calves? (tick all that apply)

Nothing	0
Isolate the sick calf	0
I use specific tools / equipment for the sick animal	0
I disinfect the tools / equipment used with the sick animal	0
I use gloves and disinfect my wellies after the contact with the sick animal	0
Other	0

Multi answer: Percentage of respondents who selected each answer option (e.g. 100% would represent that all this question's respondents chose that option)

29.a If you selected Other, please specify:

No responses

30 What would you do first?

Administer a treatment	0
Call the vet	0
Wait and check the cow frequently	0
Other	0

30.a If you selected Other, please specify:

No responses

30.b Which ones?

No responses

30.b.i Why would you choose it?

I Follow my written treatment protocol	0
I do what the vet previously advised to me	0
Because it is cheap	0
Because I am familiar with this drug	0
Other	0

30.b.i.a If you selected Other, please specify:

No responses

30.c Why would you first call the vet?

I want to do the best treatment for the cow	0
I don't know which treatment to administer	0
I am not sure if antibiotic is necessary	0
I am not sure of my diagnosis	0
Other	0

30.c.i If you selected Other, please specify:

No responses

31 Would you use the milk to feed the calves?

Appendix III – Survey PDF (Jisc)

Yes	0
No	0
Only after a milk treatment (example pasteurisation)	0

32 Which antibiotic would you choose and why?

No responses

33 How do you know which calves are treated? (tick all that apply)

I write in the treatment book	0
I mark the calves	0
I record on my smartphone	0
I remember	0
Other	0

Multi answer: Percentage of respondents who selected each answer option (e.g. 100% would represent that all this question's respondents chose that option)

33.a If you selected Other, please specify:

No responses

34 How long would you treat the calves for?

I follow my written protocols	0
I follow previous vet advice	0
I follow the instructions on the drug leaflet	0
Until the calves look well	0
Other	0

34.a If you selected Other, please specify:

No responses

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

Vaccinate cows	0
Take a faecal sample to identify the infectious agent	0
Do a prophylactic treatment	0
Other	0

35.a If you selected Other, please specify:

No responses

36 Which other action would you take to reduce the spread of the infection on farm? (tick all that apply)

Nothing	0
Cleaning and disinfecting the pens	0
Ensure colostrum intake/quality	0
Feeding sick animals at the end	0
Isolate sick animals	0
Other	0

Multi answer: Percentage of respondents who selected each answer option (e.g. 100% would represent that all this question's respondents chose that option)

36.a If you selected Other, please specify:

No responses

37 What would you do first?

Administer a treatment	0
Call the vet	0
Wait for the foot trimmer	0
Other	0

37.a If you selected Other, please specify:

No responses

37.b Which ones?

No responses

37.b.i How long would you treat the animal for?

Until improvement of the lameness	0
What it is recommended on the drug leaflet	0
What worked in my experience	0
Other	0

37.b.i.a If you selected Other, please specify:

No responses

38 What would you do first?

I administer a treatment	0
I take a milk sample	0
I call the vet	0
Other	0

38.a If you selected Other, please specify:

No responses

38.b Which antibiotic would be most appropriate in your opinion?

Not sure	0
Penicillin/Amoxycillin	0
Oxytetracycline	0
Tylosin	0
Trimethoprim/sulfadiazine	0
Ceftiofur	0
Other	0

38.b.i If you selected Other, please specify:

No responses

39 It is important to reduce antibiotic use on UK dairy farms

Strongly agree	0
Agree	0
Neither agree nor disagree	0
Disagree	0
Strongly disagree	0
I don't know	0

40 Nowadays, there is too much reliance on antibiotic use on dairy farms in the UK

Strongly agree	0
Agree	0
Neither agree nor disagree	0
Disagree	0
Strongly disagree	0
I don't know	0

41 Decreasing antibiotic usage in dairy farms can could help reducing antibiotic resistance in livestock

Strongly agree	0
Agree	0
Neither agree nor disagree	0
Disagree	0
Strongly disagree	0
I don't know	0

42 Decreasing antibiotic usage in dairy farms could help reducing antibiotic resistance in humans

Strongly agree	0
Agree	0
Neither agree nor disagree	0
Disagree	0
Strongly disagree	0
I don't know	0

43 Some antibiotics work less effectively than in the past

Strongly agree	0
Agree	0
Neither agree nor disagree	0
Disagree	0
Strongly disagree	0
I don't know	0

44 Farmers require more training on antibiotic use

Strongly agree	0
Agree	0
Neither agree nor disagree	0
Disagree	0
Strongly disagree	0
I don't know	0

45 Farm biosecurity and vaccination can reduce antibiotic use

Strongly agree	0
Agree	0
Neither agree nor disagree	0
Disagree	0
Strongly disagree	0
I don't know	0

46 It is important to have protocols for antibiotic use on farm

Strongly agree	0
Agree	0
Neither agree nor disagree	0
Disagree	0
Strongly disagree	0
I don't know	0

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

Strongly agree	0
Agree	0
Neither agree nor disagree	0
Disagree	0
Strongly disagree	0
I don't know	0

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

Strongly agree	0
Agree	0
Neither agree nor disagree	0
Disagree	0
Strongly disagree	0
I don't know	0

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

Strongly agree	0
Agree	0
Neither agree nor disagree	0
Disagree	0
Strongly disagree	0
I don't know	0

50 It is important to always respect the withdrawal period of treated animas before slaughter or including the milk in the bulk milk tank

Strongly agree	0
Agree	0
Neither agree nor disagree	0
Disagree	0
Strongly disagree	0
I don't know	0

51 I am worried about antibiotic resistance on UK dairy farm

Strongly agree	0
Agree	0
Neither agree nor disagree	0
Disagree	0
Strongly disagree	0
I don't know	0

52 What is your age?

18-35	0
36-50	0
51-65	0
Over 65	0
Prefer not to say	0

53 What is your sex?

Male	0
Female	0
Prefer not to say	0

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

Less than 5	0
6-20	0
21-40	0
More than 40	0

55 What is your highest level of education?

High school	0
Agricultural college	0
University	0
Other	0

55.a If you selected Other, please specify:

No responses

56 How many years has the dairy enterprise been operating?

Less than 5 years	0
5 to 20 years	0
20 to 40 years	0
More than 40 years	0

57 Is your dairy farm:

Conventional	0
Organic	0
In conversion to organic	0

58 Please provide an approximate number of the dairy animals on your farm:

58.1 Milking and dry cows

58.1.a Milking and dry cows - Number of animals

No responses

58.2 Replacement heifers (weaned)

58.2.a Replacement heifers (weaned) - Number of animals

No responses

58.3 Calves unweaned (male and female)

58.3.a Calves unweaned (male and female) - Number of animals

No responses

58.4 Dairy bulls

Appendix III – Survey PDF (Jisc)

58.4.a Dairy bulls - Number of animals

No responses

59 Do you have any disease-free / control accreditation? (tick all that apply)

No	0
BVD	0
Johnes	0
Lepto	0
IBR	0
Other	0

Multi answer: Percentage of respondents who selected each answer option (e.g. 100% would represent that all this question's respondents chose that option)

59.a If you selected Other, please specify:

No responses

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

Yes	0
No	0

60.a How many?

No responses

60.b Of which of the following categories? (tick all that apply)

Replacement heifers	0
Milking cow	0
Bull	0
Other	0

Multi answer: Percentage of respondents who selected each answer option (e.g. 100% would represent that all this question's respondents chose that option)

60.b.i If you selected Other, please specify:

No responses

61 Do you have other species/livestock types on farm? (tick all that apply)

No	0
Sheep	0
Beef	0
Poultry	0
Other	0

Multi answer: Percentage of respondents who selected each answer option (e.g. 100% would represent that all this question's respondents chose that option)

61.a If you selected Other, please specify:

No responses

62 What is your role in the enterprise? (tick all that apply)

Owner	0
Farm manager	0
Dairy manager	0
Herdsman/woman	0
Other	0

Multi answer: Percentage of respondents who selected each answer option (e.g. 100% would represent that all this question's respondents chose that option)

62.a If you selected Other, please specify:

No responses

Appendix III – Survey PDF (Jisc)

63 Please give an approximate value for each of the following question.

63.1 What is the annual average milk production per cow (litres)?

63.1.a What is the annual average milk production per cow (litres)? - Approximate value

No responses

63.2 What is the current geometric average somatic cell count (cells/ml)?

63.2.a What is the current geometric average somatic cell count (cells/ml)? - Approximate value

No responses

64 Who is your milk buyer?

No responses

65 Please, enter your email address if you wish to participate to the prize draw. It will only be used for this purpose and will not be associated with your responses.

No responses

Appendix III – Survey PDF (Jisc)