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Improved animal husbandry, biosecurity and vaccination as a strategy to reduce antimicrobial use

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Summary

Preventive health strategies in animal production, including biosecurity, improved husbandry practices and vaccination, are increasingly recognised as essential tools for promoting livestock health, reducing antimicrobial use (AMU) and supporting the sustainability of food systems. This narrative study synthesises current evidence on the impacts of preventive measures across pig, broiler and veal calf production systems to reduce AMU. A targeted literature search using PubMed, Scopus and Web of Science identified peer-reviewed studies assessing the effects of external and internal biosecurity practices, farm management practices and vaccination programmes on AMU. Consistent findings indicate that enhanced biosecurity is associated with reduced AMU, lower morbidity and mortality rates, and improved production outcomes. Intervention trials demonstrate that relatively low-cost structural and behavioural biosecurity upgrades can yield substantial returns on investment through reduced veterinary expenses and higher growth rates. However, context-specific variables, such as herd size, local disease pressure and stakeholder compliance, significantly influence the effectiveness of biosecurity measures. Notably, some associations between vaccination and increased AMU highlight the need for further causal research there. This article advocates preventive health and evidence-based biosecurity as pillars of antimicrobial stewardship and offers strategic recommendations to strengthen policy frameworks, improve infrastructure and promote sustainable on-farm adoption.

Keywords

Antimicrobial resistance – Antimicrobial use – Biosecurity – Livestock – Productivity – Stewardship – Vaccines.

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Introduction

Animal husbandry practices, especially in poultry, pig and cattle farming systems, have undergone substantial intensification since the 1950s, with significant differences between geographical regions. While these advances have led to increased global meat, milk and egg supplies, they have also introduced multifaceted challenges linked to food safety related issues, antimicrobial resistance (AMR), zoonotic disease transmission, reduced animal welfare and environmental degradation [1-3].

Livestock farming remains one of the largest consumers of antimicrobials globally. In 2017, AMU in animals accounted for approximately 73% of total global antimicrobial consumption [4]. Extensive AMU in food-producing animals has facilitated the emergence and dissemination of resistance, posing risks of exchange of antimicrobial resistance genes [5] between animals and transfer to humans through direct animal contact [6], environmental pathways [7] and consumption of contaminated animal-derived food products [8]. In 2019, AMR infections were associated with approximately 1.27 million deaths globally [9], with projections indicating a potential rise to around 8–9 million annual deaths if effective interventions are not implemented [10]. Besides this, AMR may also cause therapy failure in animals [11]. Thus, reducing AMU is critical to curb the emergence of AMR and protect animal and public health [12,13]. While the dynamics of AMR are complex, shaped by interconnected reservoirs and co-selection pressures [14], evidence suggests that reducing AMU in livestock remains a critical and effective step towards mitigating AMR in both animals [15] and humans [16]. Despite global momentum in addressing AMR through national action plans and international guidelines, the non-therapeutic use of antimicrobials as growth promoters, prophylactics and metaphylactics remains frequent, especially outside the European Union, where these practices have been prohibited since 2006 and 2022, respectively, and particularly in intensive systems where preventive health measures are poorly adopted [17-19].

Previous studies have shown that livestock AMU is influenced by two main categories of factors: socio-economic and behavioural aspects related to farmers and veterinarians, and technical farm characteristics. The latter includes housing, internal and external biosecurity, nutrition, environmental and microclimate conditions of barns, farm size, and overall management practices that impact disease risk [20,21]. Researchers have reviewed a range of risk factors influencing AMU, including species-specific analyses in calves, pigs and poultry [20], the impact of farm biosecurity practices [22], and broader cross-species assessments across the European Union [23]. Other studies have focused on AMU-reduction interventions, highlighting the interplay between technical and behavioural factors [24,25]. Additionally, poor biosecurity and suboptimal farm management have been identified as key contributors to increased AMR in broilers [26].

In this context, interventions should shift the focus from reactive treatment to proactive health management, aiming to reduce disease incidence and transmission at its source. Core components of proactive health management include biosecurity measures, vaccination programmes, improved husbandry practices, early disease detection, nutritional management, and education and training of farm personnel [27]. The concept of biosecurity has gained prominence as a cost-effective, sustainable strategy that addresses both endemic and emerging disease threats while supporting productivity and public health goals through reduced AMU and improved animal welfare [22,28-30]. Nonetheless, adoption of biosecurity measures remains inconsistent, often hindered by farmers' perceptions of low practicality, unclear financial return and lack of support. Studies have shown that willingness to adopt biosecurity practices is inversely related to their perceived or actual cost [31,32]. Furthermore, a lack of accessible information on the cost–benefit profile of biosecurity interventions has prevented widespread adoption.

With this background, this study aims to assess the available evidence on the impact of improved technical farm characteristics and rearing practices such as animal husbandry, biosecurity and vaccination at the farm level on AMU in farm animals. Specifically, this study focused on pigs, broilers and veal calves, as chicken and pig meat represent the two primary sources of animal protein worldwide, followed by cattle [33]. Among cattle production systems, veal calf farms (i.e. farms for rearing surplus calves destined for veal meat) have been reported to exhibit particularly high levels of AMU and AMR [34,35].

Methodology

To gather relevant literature, a comprehensive search was conducted across three scientific databases: PubMed, Scopus and Web of Science. The search strategy involved combinations of keywords such as 'biosecurity', 'antimicrobial use', 'antibiotic use', 'antibiotic consumption', 'antimicrobial consumption', 'factor', 'driver' and 'association', along with livestock species terms including 'pigs', 'poultry', 'broilers', 'calves' and 'veal'. This narrative study employed a purposive and convenience-based selection strategy to identify studies relevant to the targeted topic, namely, the effects of technical farm characteristics such as biosecurity, animal husbandry and vaccination practices on AMU. Priority was given to studies in which AMU outcomes were measured at the farm level and with a multivariable model adjusting for potential confounders. The study focused specifically on pigs, broilers and veal calves, given their relatively high levels of AMU and their significance as major sources of animal protein.

Results

Effect of farm characteristics on antimicrobial use

Understanding farm characteristics can provide essential insights into effective AMU management and AMR mitigation. Numerous studies have investigated diverse farm factors. Table I presents the farm characteristics found to influence AMU significantly. Herd size emerged as the most frequently investigated factor across pigs, broilers and veal calves, with results remaining inconclusive for all three species. Specifically, for pigs, the majority of researchers identified larger herd size as a risk factor or smaller herd size as protective, while some studies reported the opposite. Also in veal calves, some studies reported larger herd size as protective against AMU [36,37], whereas another study noted it as a risk factor [38]. Broiler studies have shown mixed results regarding the relationship between flock size and AMU. In some cases, a higher number of birds was associated with reduced AMU, particularly when effective biosecurity practices were in place. In other contexts, average flock size was found to be protective only under certain management conditions [16,39]. However, other analyses suggested that larger flock sizes could also pose a risk for increased AMU, depending on the model used and the time frame considered [20].

The concept of herd size as a risk factor aligns with previous studies demonstrating that increased animal numbers are associated with higher infection rates in pigs [40,41], broilers [42] and veal calves [36]. Larger herd sizes were also shown to be associated with increased disease incidence [43-46] and higher mortality [38,47,48], ultimately elevating AMU. Yet, a Belgian biosecurity survey reported that over 95% of low-biosecurity pig farms were small, whereas 72% of high-biosecurity farms were large [49]. Other studies reinforced a positive correlation between herd size and biosecurity level [49-52]. This is likely due to higher infection risks and greater economic capability to invest in preventive measures on large farms.

Although herd size inherently increases infection risk [81,82], effective biosecurity measures can mitigate it. The intricate relationship between herd size and biosecurity makes it difficult to isolate the direct impact of the former on AMU. This complexity intensifies when AMU metrics, adjusted for animal numbers, are applied. Therefore, while some larger farms demonstrate protective effects in terms of AMU measured in defined daily dose animal units, the scenario might differ when considering net antimicrobial quantities. Future research examining AMU associations with herd size or

AMR may need to account for these distinctions, as resistance also depends on net AMU in animals.

Effect of biosecurity on disease prevention and antimicrobial use reduction

Especially in poultry and pig production, global food systems, shaped by industrial intensification and efficiency-driven models, have produced genetically uniform, high-density animal populations. This uniformity increases vulnerability to disease outbreaks and zoonotic spillover due to the lack of biodiversity 'firebreaks' [83,84]. In response, there is a growing shift within livestock systems towards health-oriented management, where biosecurity has emerged as an important pillar of antimicrobial stewardship [85]. Strengthening on-farm preventive measures, improving biosecurity practices and addressing the behavioural drivers of AMU are increasingly recognised as effective strategies to reduce reliance on antimicrobials in these production systems. Table II summarises various biosecurity and husbandry factors influencing AMU across livestock species.

In swine production, biosecurity and AMU are tightly linked. Farms with strong internal biosecurity, such as all-in/all-out pig flow, strict cleaning routines and dedicated pens, experience significantly fewer outbreaks and require fewer antimicrobials [86-88]. A recent scoping review by Dhaka *et al.* [22] analysing 27 studies across pig, poultry and cattle systems found that 81.5% reported a positive association between better biosecurity and/or management and lower AMU. Key interventions included air quality control, separation of sick animals and structured introduction protocols.

External biosecurity factors, such as farm isolation, distance from other livestock operations and pig density, also have a documented impact on AMU [85,89]. Mixing pigs from different sources [68], proximity (<500 meters) to other pig farms [53,55] and high surrounding livestock density are all associated with increased AMU [21]. Historical outbreak data support the importance of spatial separation. Elbers *et al.* [90] demonstrated that the likelihood of classical swine fever spread was inversely proportional to distance from infected herds in the Netherlands. In the United States of America, studies on porcine reproductive and respiratory syndrome virus (PRRSV) revealed that 45% of outbreaks occurred within 500 meters but only 2% occurred beyond 1 kilometre [91,92].

Notably, the majority of biosecurity factors influencing AMU have been identified through Biocheck.UGent. This is a risk-based assessment tool that allows for the quantification and comparison of the biosecurity status of herds within and between countries [85]. In a study by Raash *et al.* [57], a low external biosecurity score was identified as a risk factor for AMU. Yet, a high internal biosecurity score was also associated with higher AMU, calling for cautious interpretation of such scores, as they may mask differences in farm practices. In other words, farms may share the same score despite applying different practices, making it vital to pinpoint which biosecurity measures affect AMU for targeted advice. Disease management also plays a pivotal role. Farms with consistent protocols for treating sick animals, regular veterinary visits (≥2/year) and workflows ensuring healthy pigs are handled before sick ones showed reduced AMU [51,68,69].

Husbandry practices, which involve the care and handling of animals, also influence AMU. In domestic animals, higher animal welfare is generally associated with lower AMU [93]. For instance, key husbandry factors for pigs are cross-fostering, weaning age and farrowing rhythm. Repeated cross-fostering increases stress and injury in piglets, raising AMU, whereas early, one-time fostering shows fewer negative effects [64,94,95]. Higher weaning ages (28–35 days) promote stronger piglets with better immunity and lower antimicrobial requirements [21,77,88,96,97]. A farrowing rhythm of five weeks was associated with reduced AMU due to reduced overlap between batches [21,64,98]. Arnold *et al.* [68] reported that the absence of an all-in/all-out system and clean working protocols led to significantly higher oral AMU.

Poultry systems exhibit a clear link between strong biosecurity and reduced disease/AMU. Controlled barn access, boot disinfection and stringent sanitation practices significantly lower pathogen load [99,100]. Farms implementing these practices consistently report better feed conversion, reduced mortality and improved flock performance. Broiler density in surrounding areas is an established risk factor for AMU [101]. Spatial analyses confirm that outbreaks on nearby farms elevate risk [44,82,102], emphasising the importance of external biosecurity in poultry-dense regions. Absence of disinfection baths and poorly maintained water systems were also shown to significantly increase AMU in broiler farms [39,103]. In contrast, poor biosecurity practices lead to higher AMU, more frequent disease episodes and lower productivity [104]. Though profit margins are tighter than in pig production, avoiding catastrophic losses (e.g. from avian influenza) through biosecurity yields high long-term economic returns [105].

Cattle operations benefit from targeted biosecurity protocols. External measures, such as visitor restrictions, dedicated clothing and animal quarantine, have been linked to reduced prevalence of chronic diseases like bovine viral diarrhoea and infectious bovine rhinotracheitis [106,107]. Internal improvements, such as the use of footbaths, lower environmental contamination and calf disease [108]. A study showed that introducing a 30-day quarantine for new arrivals halved respiratory disease treatments [109]. These findings reinforce the concept that even simple, well-executed preventive measures can significantly reduce AMU. The veal calf systems face unique biosecurity challenges due to the mixing of young calves from multiple origins. This high commingling rate contributes to historically elevated AMU. Researchers observed that group size, absence of quarantine, and shared ventilation systems were positively associated with AMU [77]. Conversely, all-in/all-out management, strict cleaning between batches, and calf isolation significantly lowered AMU and disease incidence. Additional risk factors include shared airspaces and the lack of clinical examination on calf arrival [38].

Across all species, intervention trials and economic studies affirm that biosecurity investments pay off. Postma *et al.* [110] documented a 50% AMU reduction in pigs without performance losses after an intensive coaching trajectory towards better biosecurity. Enhanced biosecurity practices in Flanders yielded net profits of € 2–3 per finisher pig [111], and even modest feed efficiency improvements offset costs [112]. Nevertheless, the relationship between biosecurity and AMU is not always linear. For example, Backhans *et al.* [54] reported no clear association in Swedish pig farms, possibly due to already high baseline health and biosecurity levels. Contextual factors, like baseline disease prevalence, farm density and regional veterinary norms, can influence biosecurity effectiveness [20].

Stakeholder behaviours, particularly among farmers and veterinarians, also critically determine AMU patterns. Farmers with higher awareness of AMR and stewardship are more likely to adopt preventive practices and reduce AMU [88], while over-the-counter antimicrobial availability and pharmaceutical marketing can contribute to misuse [39]. Moreover, socio-economic factors such as farm profitability, veterinary access and market incentives remain understudied but likely shape AMU [20]. Overall, farm biosecurity is widely acknowledged as a critical control point to reduce AMU [22,85]. As illustrated in Figure 1, a conceptual framework of AMU determinants in livestock production, farm biosecurity (both internal and external), preventive health measures, animal-level risk factors and stakeholder behaviours all interact to influence AMU. Improving on-farm preventive measures and biosecurity, while addressing human behaviours, is seen as a promising approach to reduce AMU in these sectors.

In the long list of observed associations between improved biosecurity components and reduced AMU, sometimes unexpected and/or biologically difficult to explain associations are observed. For instance, in a study on broilers, the cleaning/disinfection of the concrete perimeter was found to be a risk factor for increased AMU [113], whereas this is expected to be a protective measure. Also, in a study in veal calves, never disinfecting the stable was found to be associated with lower AMU [64]. Possibly these findings are affected by unobserved confounders and other types of biases that are encountered frequently in observational studies (e.g. recall bias, sampling bias). Only when risk factors are observed with consistency between studies and preferably with meta-analytical estimates is there a need to dig deeper for the plausible biological explanations behind them.

Impact of vaccination on animal health and antimicrobial use

The relationship between vaccination and AMU is multifaceted and often influenced by contextual factors, such as disease burden, farm management and farmers' attitudes. The key literature findings on the link between vaccination and AMU are summarised in Table III.

In pig production systems, extensive research has evaluated the association between AMU and specific vaccines, such as against porcine circovirus type 2 (PCV2), *Actinobacillus pleuropneumoniae*, PRRSV, influenza A virus (IAV), *Lawsonia intracellularis*, *Escherichia coli* and *Mycoplasma hyopneumoniae* [21,88,114,145]. Several studies reported that herds vaccinated against PRRSV, PCV2, *A. pleuropneumoniae* or IAV had higher AMU compared to unvaccinated herds. For example, Kruse *et al.* [146] observed elevated AMU in herds vaccinated against PRRSV and PCV2, while O'Neill *et al.* [114] found similar trends for IAV. Furthermore, Postma *et al.* [88] showed that AMU increased with the number of pathogens vaccinated against, suggesting a possible association between disease complexity and AMU. Interestingly, the combined use of vaccines, for instance *L. intracellularis* and PRRSV, was also associated with higher AMU when compared to vaccination against a single pathogen or no vaccination [145].

In broiler systems, the evidence is more limited but points to a similar pattern. Hughes *et al.* [132] reported that vaccination against infectious bursal disease was associated with higher AMU, while Mallioris *et al.* [39] found that strict compliance with vaccination protocols for non-officially controlled diseases also correlated with increased AMU. Similarly, in veal calves, Schnyder *et al.* [140] identified a positive association between vaccination against bovine respiratory disease and AMU.

It is important to emphasise that these associations do not imply that vaccines are ineffective. Rather, they likely reflect residual confounding or reverse causality as farms encountering more disease problems are both more likely to vaccinate and to use antimicrobials [58,145,146]. This has also been supported by a European Medicines Agency and European Food Safety Authority panel [147], but the economic incentives for vaccine sales, especially given the restrictions taking place in the sales of antimicrobials, cannot be disregarded. Also, although several of the reported vaccines here are for viral pathogens, they can still be associated with AMU as several diseases are polymicrobial in nature with secondary bacterial infections [148]. Farmers' attitudes may also play a role: those who are proactive about disease prevention may incorporate both vaccines and antimicrobials into an intensive health-management strategy [145]. Vaccine failure (due to improper storage or application, or suboptimal immunogenicity) can lead to persistent infections requiring antimicrobial treatment [149,150]. Moreover, effective vaccination outcomes are contingent on good husbandry and stringent biosecurity practices; without these, vaccine efficacy can be compromised [151]. Additional confounders, such as needle hygiene and application technique, may further affect outcomes [152].

Recommendations to strengthen farm biosecurity and improve vaccination

Despite the well-documented benefits of farm biosecurity and preventive strategies in reducing disease burden and AMU, challenges are often encountered in their practical implementation. Adoption is highly variable across farm types and regions, influenced by factors such as cost, labour availability, risk perception and farmer awareness. Particularly in smallholder and resource-limited settings, biosecurity practices may be selectively or inconsistently applied due to financial and operational constraints [22]. Moreover, the invisibility of prevented infections can diminish motivation for sustained compliance. Biosecurity's success also hinges on its integration with other preventive interventions and its adaptability to local epidemiological contexts. Above all, its effectiveness depends on human behaviour, as no plan, however sound, is effective unless rigorously implemented. To address these gaps, a combination of structural, educational, policy-level and context-specific strategies is necessary. Table IV summarises key recommendations to improve biosecurity adoption and impact across livestock systems. The possible solutions require a mix of strategies including regulation, outreach, incentives and demonstrable evidence that the benefits of biosecurity outweigh the costs [51,122,154].

Besides improved biosecurity, a more judicious use of vaccines is also required. The observed associations between increased vaccination and higher AMU suggest that antimicrobial therapy and vaccination are often applied simultaneously. This may indicate that vaccines are not always sufficiently effective, or that antimicrobials are continued for too long after vaccination has been initiated. Often, the latter seems to be the case. Therefore, veterinarians and farmers should be supported and encouraged to gradually reduce AMU once effective preventive measures, such as biosecurity and vaccination, have been implemented. In addition, more intervention studies are needed on farms that introduce vaccination following proper diagnostics, with subsequent monitoring of AMU.

Study limitations

This study was conducted as a purposive, narrative synthesis and does not fulfil the criteria of a systematic review. The reliance on observational and cross-sectional data in many studies also precludes definitive causal inferences regarding biosecurity, management and vaccination impacts on AMU and productivity. Before inclusion, the studies were carefully assessed for their quality (e.g. AMU quantification method, farm data reporting method, sample size, use of multivariable models in the analysis), but this assessment was not structured systematically for reporting. Moreover, geographic representation was uneven, with the majority of evidence emerging from high-income settings (46 *versus* 13 papers), potentially limiting applicability to low- and middle-income countries (LMICs), where production type, structural constraints and disease risks differ. In LMICs research on this specific topic was more limited, with several studies focusing either on describing just AMU data [155] or on behavioural aspects of the farmer towards AMU or on factors for AMR. Further research using standardised biosecurity assessment tools and longitudinal study designs is needed to strengthen the evidence base. As seen from the studies included in this article, such tools (e.g. Biocheck.UGent) are already being used in LMICs to assess biosecurity [104].

Conclusion

Proper farm management and biosecurity are cornerstone strategies for sustaining livestock health while minimising antimicrobial dependence. Across species and production systems, good farm management and stronger biosecurity reliably yield fewer infections and disease outbreaks, which in turn reduces the need for antimicrobial treatments. This aligns with global antimicrobial stewardship efforts by preserving the efficacy of critical drugs through reduced use. While challenges to implementation persist, vaccination, farm management and biosecurity should be central in animal husbandry. By investing in these preventive measures, the livestock industry can simultaneously improve animal welfare, ensure productivity and help combat the threat of AMR in a sustainable manner

L’amélioration des pratiques d’élevage, la biosécurité et la vaccination en tant que stratégies pour réduire l’utilisation des agents antimicrobiens

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Résumé

Il est désormais largement admis que pour préserver la santé du bétail tout en réduisant l’utilisation des agents antimicrobiens (UAM) et en soutenant la durabilité des systèmes de production alimentaire, les stratégies de santé animale préventives déployées dans les élevages constituent des outils essentiels, en particulier celles qui portent sur la biosécurité, l’amélioration des pratiques d’élevage et la vaccination. Cet examen narratif présente une synthèse des connaissances empiriques actuelles concernant les effets des mesures de prévention appliquées dans les systèmes de production de porcs, de poulets de chair et de veaux de boucherie en termes de réduction de l’UAM. À partir d’une recherche documentaire ciblée sur PubMed, Scopus et Web of Science, les auteurs ont recensé les études publiées dans des journaux à comité de lecture consacrées à l’évaluation des effets respectifs sur l’UAM des pratiques externes et internes de biosécurité, des méthodes de gestion des élevages et des programmes de vaccination. Les résultats concordants de ces évaluations indiquent qu’un renforcement de la biosécurité s’accompagne d’une réduction de l’UAM, d’une baisse des taux de morbidité et de mortalité, et de meilleurs rendements des élevages. Des études interventionnelles ont également montré qu’un renforcement de la biosécurité au moyen de mesures tant structurelles que comportementales relativement peu coûteuses peut offrir des retours sur investissement substantiels, par la réduction des dépenses vétérinaires et l’augmentation des performances de croissance qui lui sont associées. Cependant, l’efficacité des mesures de biosécurité dépend aussi de variables spécifiques au contexte, qu’il s’agisse de la taille du cheptel, de la pression infectieuse locale ou du niveau d’adhésion des parties prenantes, entre autres. Il conviendra notamment d’expliquer, au moyen de recherches causales plus poussées, l’association observée dans certaines configurations entre l’usage de la vaccination et une hausse de l’UAM. Cet examen plaide en faveur de la santé préventive et de la biosécurité fondée sur des éléments probants en tant que piliers d’une bonne gestion des antimicrobiens ; les auteurs ajoutent quelques recommandations de nature stratégique afin de renforcer les cadres politiques, d’améliorer les infrastructures et de favoriser une appropriation durable de ces pratiques au niveau des élevages.

Mots-clés

Animaux d’élevage – Biosécurité – Bon usage des antimicrobiens – Productivité – Résistance aux agents antimicrobiens – Utilisation des agents antimicrobiens – Vaccins.

Prácticas ganaderas mejoradas, bioseguridad y vacunación como estrategia para reducir el uso de antimicrobianos

P. Mallioris, P. Dhaka, I. Makovska, N. van Sabben, J.A. Wagenaar, A. Stegeman, L. Mughini-Gras & J. Dewulf

Resumen

Las estrategias sanitarias preventivas en materia de producción animal, como la bioseguridad, la mejora de las prácticas ganaderas y la vacunación, son cada vez más reconocidas como herramientas esenciales para promover la sanidad del ganado, reducir el uso de antimicrobianos (UAM) y acompañar la sostenibilidad de los sistemas alimentarios. Esta revisión narrativa es una síntesis de las pruebas actuales sobre las repercusiones de las medidas preventivas en los sistemas de producción de cerdos, pollos de engorde y terneros para reducir el UAM. A través de una búsqueda bibliográfica específica en PubMed, Scopus y Web of Science, se identificaron estudios revisados por pares que evaluaban las consecuencias de las prácticas de bioseguridad externas e internas, las prácticas de gestión de las explotaciones y los programas de vacunación sobre el UAM. Los resultados constantes indican que la mejora de medidas de bioseguridad está relacionada con una reducción del UAM, menores tasas de morbilidad y mortalidad, y mejores resultados de la producción. Si bien los ensayos de intervención demuestran que las mejoras estructurales y de comportamiento en materia de bioseguridad, relativamente económicas, permitirían generar un rendimiento sustancial de la inversión gracias a la reducción de los gastos veterinarios y al aumento de las tasas de crecimiento, las variables específicas del contexto, como el tamaño del rebaño, la presión de las enfermedades locales y el cumplimiento por parte de las partes interesadas, tiene una influencia significativa en la eficacia de las medidas de bioseguridad. Cabe destacar que algunas asociaciones entre la vacunación y el aumento del UAM ponen de relieve la necesidad de continuar investigando las causas. La presente publicación promueve la aplicación de medidas sanitarias preventivas y la bioseguridad basada en pruebas como pilares de la optimización de los antimicrobianos y ofrece recomendaciones estratégicas para reforzar los marcos reglamentarios, mejorar la infraestructura y fomentar la adopción sostenible en las explotaciones.

Palabras clave

Bioseguridad – Ganado – Optimización – Productividad – Resistencia a los antimicrobianos – Uso de antimicrobianos – Vacunas.

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Table I

Farm-related factors influencing AMU in pigs, broilers and veal calves; factors treated as categorical contain the reference category in parenthesis, the others are continuous

Species/category	Factors	Reference
Pigs		
Herd size	**Risk**	
	Number of pigs	[53]
	Number of sows present	[53]
	Number of sows	[54]
	Number of pigs (in 1,000)	[55]
	Farm size	[56]
	LOG number of sows	[57]
	Medium (7,500–14,999) herd size (ref: smaller)	[58]
	Large (>15,000) herd size (ref: smaller)	[58]
	Herd size (>median)	[59]
	Number of reared pigs <5,000 (ref: >5,000)	[60]
	Herd size*	[61]
	Protective	
	Herd size: ≤1000 (ref: >1,000)	[62]
	Largest herds (ref: small herds)	[63]
	Large herds (ref: small herds)	[63]
	Moderate herds (ref: small herds)	[63]
	Number of animals	[64]
	Herd size of conventional herds	[65]
	Herd size of specific pathogen-free farms	[65]
	Large herds (ref: small herds)	[66]
Other farm characteristics	**Risk**	
	Type of farm (nursery–finisher farms *vs* other farm types)	[67]
	Only fatteners (ref: farrow to finish)	[62]
	External analysis of production parameters	[68]
	No herd book performance data analysis	[69]
	Herd type (piglets producing herds *vs* farrow-to-finish herds)	[66]
	Type of farm (conventional farms *vs* integrated farms and grandparent farms)	[70]
	Protective	
	Number of employees per 100 present sows	[21]
	Farrow-to-finish farm (ref: mixed farm)	[53]
	Specialised fattening pig farm (ref: mixed farm)	[53]
	Farm system: specialised sow farm (ref: farrow to finish)	[53]
	The farmer working on other farms	[68]
	Poor condition farm building	[71]

Species/category	Factors	Reference
Broilers		
Herd size	**Risk**	
	Number of chickens**	[72]
	Protective	
	Farm size	[16]
	Number of chickens**	[72]
	Number of flocks total	[72]
	Average number of chicks per round	[39]
	Farm size	[73]
Other farm characteristics	**Risk**	
	Semi-industrial or Industrial production (ref: household farm)	[74]
	Protective	
	Number of people working at the poultry farm in total	[39]
	Slower growing breeds	[72]
	Breed type (broiler, Sonali; ref: layer)	[75]
	Portion of broilers	[73]
	Meat production type (*vs* layer and dual purpose)	[76]
Veal calves		
Herd size	**Risk**	
	Two-fold increase in lot size	[36]
	Herd size	[38]
	High dairy cattle density in the province where farm is located	[77]
	Farm size	[78]
	Protective	
	Size of integration (larger *vs* smaller)	[37]
Other farm characteristics	**Risk**	
	Number of suppliers	[78]
	Protective	
	Proportion of crossbred bulls	[78]
	Holstein Friesian (HF) breed (ref: Belgian Blue (BB))	[79]
	HFxBB crossbreed (ref: BB)	[79]
	HF (ref: non-HFxBB crossbreeds)	[80]
	HFxBB crossbreeds (ref: non-HFxBB crossbreeds)	[80]

*In farms with finishers, the cluster with higher antimicrobial use (AMU) contains more large farms than the cluster with lower AMU, but in farms with weaners, the cluster with higher AMU contains more medium-sized farms than the cluster with lower AMU.

**Higher number of chickens was associated with an increased likelihood of using AMU, but appeared as a protective factor when AMU was expressed as an annual AMU rate.

Table II

Biosecurity and husbandry practice factors influencing antimicrobial use in livestock

Category	Type	Factor	Reference
Pigs			
External biosecurity	Risk	Mixing pigs from different suppliers within the same pen	[68]
		Distance to next pig farm <500 m	[68]
		Score vermin and bird control	[114]
		Number of livestock farms in county	[55]
		Pig density in county	[55]
	Protective	Number of farms with >100 livestock units	[55]
		Good site conditions	[115]
		Farm environment score (low human density, remote)	[57]
		Pathogen-specific biosecurity measures targeting *Salmonella*	[116]
		General external + internal biosecurity improvements	[112]
		Higher weaning age	[117]
		Visitor hygiene protocols and disinfection of incoming supplies	[118]
		High scores in biosecurity, batch management and pre-weaning handling	[119]
Internal biosecurity	Risk	Low internal biosecurity score	[57]
		Lack of all-in/all-out	[69]
		Weekly needle change for sows	[64]
		Organic-extensive *vs* intensive system biosecurity	[120]
		Higher internal biosecurity scores	[66]
	Protective	Next Generation Biosecurity complete herds	[121]
		Farm-specific coaching for raised-without-antibiotics status	[59]
		Closed production system	[69]
		Higher internal/external biosecurity improves average daily weight gain and reduces mortality	[122]
		Improved external, all-in/all-out, pen separation	[115]
		Ceasing cephalosporin use and hygiene locks	[122]
		Yellow Card policy (↑vaccination, ↓group meds)	[123]
		Higher internal biosecurity + vaccination in sparse areas	[86]
		Herd-specific preventive interventions	[124]
		Guided internal/external biosecurity + vaccination	[110]
		Post-weaning mortality reduction via improved management	[87]
		Hygiene in water, feeding, vet visits	[69]
		African swine fever prevention biosecurity (segregation, cleaning)	[124]
		Internal biosecurity strongest predictor of antimicrobial use	[64]
		Strict compartmentalisation of pig groups, controlled pig flow and no reintroduction of returning pigs	[125]
		Rigorous pig flow and internal biosecurity management	[126]
Husbandry practices	Risk	Cross-fostering	[94]
		Fully slatted floors	[77,127]
		Routine vet assessment: poor drinking systems, high density	[71]
		Prophylactic and non-judicious antimicrobial use	[128]
		Inspection of sick animals takes place at least twice a day with immediate isolation	[77]
		The equipment is stored and used specifically for each barn separately	[77]
		Equipment is disinfected upon arrival on farm	[77]
		A hygiene lock is present for each building	[77]
		Equipment from other farms is always cleaned and disinfected before use	[77]
		Presence of disinfection foot baths on the farm	[77]
		A hygiene lock is present for each building	[77]
		Presence of loading bay	[77]
		Type of grid on weaner's floor is fully slatted (ref: fully solid)	[77]
		Inspection of sick animals takes place at least twice a day with immediate isolation	[77]
		Density in weaners is above requirements respective to the type of production	[77]
		Conventional farm	[77]
	Protective	Limited piglet suppliers, full slatted floors, reduced density	[129]
		Improved housing, water, hygiene, education	[130]
		Piglets placed per litter	[64]
		Organic farm status and longer lactation period	[77]
		Changing needles	[131]
		The farrowing rhythm is every 1, 2 or 3 weeks (ref: 4 or 5)	[77]
		Only oestrus-searched boars present and supplied from external farm	[77]
		Aggressive behaviour score between weaned piglets	[77]
		Open sow period length (days)	[77]

Category	Type	Factor	Reference
		Lactation period length (days)	[77]
Poultry (mainly broilers)			
External biosecurity	Risk	Multiple hatcheries supplying (therapeutic)	[132]
		Poultry density (area)	[101]
		Insufficient biosecurity protocols	[133]
		Non-dipping of feet before house entry	[134]
		Wild birds enter poultry house	[135]
		Poor biosecurity score	[136]
	Protective	Multiple hatcheries supplying (prophylactic)	[132]
		Preventive measures for material supply	[39]
		Visitors allowed into stables	[39]
		Natural water source <1 km	[39]
		External biosecurity score	[104]
		All-in/all-out	[137]
Internal biosecurity	Risk	Stocking density >32,914 flock size	[72]
		Cleaning/disinfection of concrete perimeter	[113]
		Poor condition of medicinal reservoir	[39]
		Poor farm sanitisation	[134]
		Use of standing water (not tap water)	[133]
	Protective	≥38 kg/m2 poultry density	[39]
		Stable-specific clothing available	[39]
		Materials stored per stable	[39]
		Farm hygiene lock present	[39]
		Clean/dirty area separation and staff training	[138]
		Internal biosecurity score	[104]
Husbandry practices	Risk	Intermediate unloading	[72]
		Thicker litter	[113]
		Higher slaughter weight	[132]
		Free range *vs* intensive management	[133]
		Farm fenced	[139]
		Location of chicken feed store (in separate room)	[139]
		Higher stress levels	[136]
	Protective	Number of flocks per barn	[72]
		Chicken paper with starter feed	[113]
		Herbal preventive drugs	[113]
		Average rounds per year	[39]
		Chicken feed storage (elevated)	[139]
Veal calves			
External biosecurity	Risk	No clinical exam on arrival	[48]
		No quarantine on arrival	[48], [140]
Internal biosecurity	Risk	Shared air space between groups	[48]
		Poor ventilation practices	[77]
	Protective	Never disinfecting the stable	[64]
		Better cleaning/disinfection of water pipes	[39]
Husbandry practices	Risk	Straw provided for bedding	[64]
		Number of calves per pen, feeding mode (6–10, trough bucket)	[141]
		Separate feeding and laying areas	[48]
		Outdoor access pen	[140]
		High maximal group size	[142]
		Regrouping starter calves for teat access	[77]
		Feeding of waste milk to calves	[143]
		Fattening phase takes place on farm	[144]
		Score for quality of cleaning and disinfecting the water pipes (ref: not cleaned and disinfected)	[144]
		Starters placed in the same pen as their baby boxes	[144]
		Longer length of period (days) in which milk was given only once a day	[144]
	Protective	Fewer calves per drinking nipple	[140]
		Longer fattening period	[48]
		Sorting calves within same compartment and prolonged once-a-day milk feeding before weaning	[77]
		Presence of a calving box in the dairy farm	[143]
		Apart from weight, starters also sorted for teat access	[144]
		Barn checked with smoke for proper air circulation (ref: no)	[144]
		Dairy cattle density in farm's province	[144]

Table III

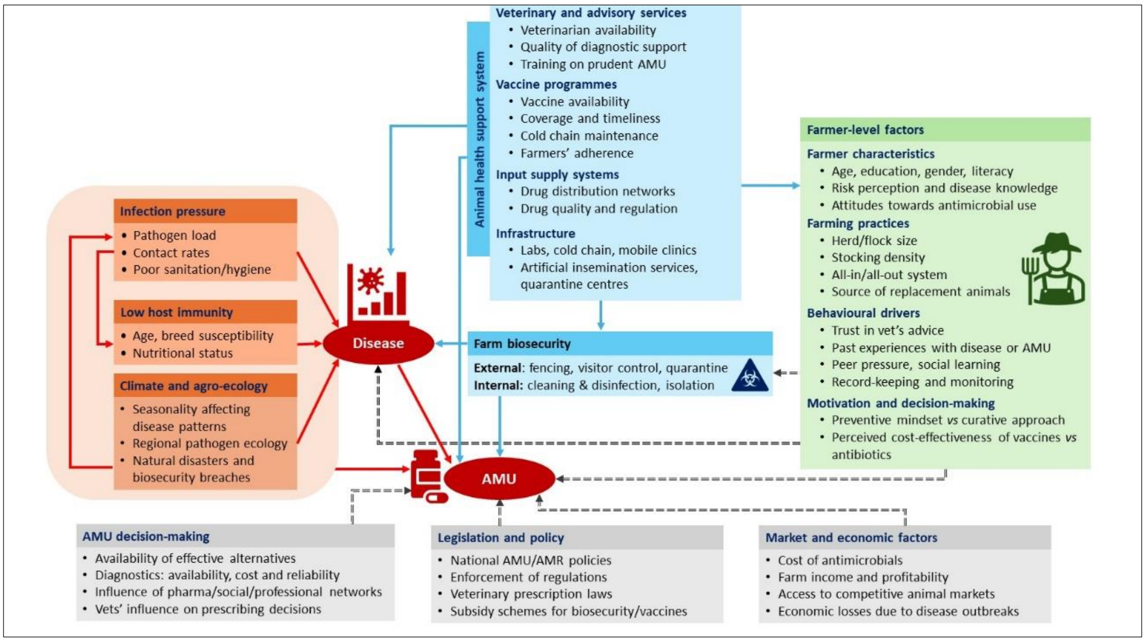
Vaccination factors influencing antimicrobial use in pigs, broilers and veal calves

Species/category	Factors	Reference
Pigs		
Vaccination	**Risk**	
	PCV2 vaccination	[146]
	APP vaccination	[146]
	PRRS vaccination	[146]
	IAV vaccination (ref: no)	[114]
	Pathogens vaccinated	[88]
	Vaccination against *Escherichia coli*	[21]
	APP vaccination	[145]
	LAW+PRRS+ *vs* LAW-PRRS-	[145]
	LAW+PRRS+ *vs* LAW-PRRS+	[145]
	LAW+PRRS+ *vs* LAW+PRRS-	[145]
	PCV2 = 1 & MYC = 0 & LAW = 0	[58]
	PCV2 = 0 & MYC = 1 & LAW = 0	[58]
	PCV2 = 0 & MYC = 0 & LAW = 1	[58]
	PCV2 = 1 & MYC = 1 & LAW = 0	[58]
	PCV2 = 1 & MYC = 1 & LAW = 1	[58]
	PCV2 = 1 & MYC = 0 & LAW = 1	[58]
	PPRS and *Streptococcus suis*	[77]
	PRRS vaccination in sucklings	[77]
	Mycoplasma vaccination in sows	[77]
	Protective	
	PCV2 = 0 & MYC = 1 & LAW = 1	[58]
	PCV2, PRRSV, *E. coli* and *Mycoplasma hyopneumoniae*	[152]
	E. coli vaccination in sows	[77]
Broilers		
Vaccination	**Risk**	
	Vaccination against infectious bursal disease	[132]
	Compliance with a vaccination protocol for non-officially controlled diseases	[39]
	Protective	
	Vaccination against *E. coli* reduced colibacillosis-related mortality in broilers	[153]
Veal calves		
Vaccination	**Risk**	
	Vaccination against BRD	[140]

APP: *Actinobacillus pleuropneumoniae*
BRD: bovine respiratory disease
E. coli: *Escherichia coli*
IAV: influenza A virus
LAW: *Lawsonia intracellularis*
MYC *Mycoplasma hyopneumoniae*
PCV2: porcine circovirus type 2
PRRSV/PRRS: porcine reproductive and respiratory syndrome virus

Figure 1

Conceptual framework illustrating drivers of antimicrobial use in livestock systems and the role of farm biosecurity



Arrows represent the direction and type of influence. Blue arrows indicate a positive effect, i.e. the factor contributes to AMU reduction or improved biosecurity. Red arrows indicate a negative effect, i.e. the factor increases AMU or disease risk. Dashed black arrows indicate context-dependent effects, which can be either positive or negative based on specific circumstances (e.g. farmer economic status or veterinary influence).

AMU: antimicrobial use
AMR: antimicrobial resistance

Table IV

Strategic recommendations for strengthening farm biosecurity and preventive practices

A. Knowledge and capacity	**B. Structural and operational measures**
– Implement continuous training/coaching on biosecurity, antimicrobial use risks, and zoonoses	– Ensure functional infrastructure: footbaths, fencing, disinfection zones
– Promote participatory learning models (e.g. farmer field schools)	– Introduce quarantine pens and separate sick animal areas
– Develop standard operating procedures and visual aids for daily routines	– Improve farm waste management, water sanitation and feed hygiene
– Integrate digital tools like Biocheck.UGent for biosecurity education and self-assessment	– Encourage affordable innovations for low-resource farms (e.g. low-cost hand/foot sanitation stations using chlorine solution buckets)
C. Behavioural and socio-economic incentives	**D. Policy, surveillance and One Health integration**
– Use behavioural nudges (reminders, signage, checklists) to reinforce habits	– Develop national livestock biosecurity frameworks and monitoring systems
– Recognise compliant farms (certification, awards, branding) to foster peer motivation	– Include biosecurity metrics in antimicrobial resistance stewardship policies and surveillance programmes
– Offer microgrants/subsidies for implementing key biosecurity components	– Foster coordination among veterinary, public health and environmental sectors
– Assess socio-economic barriers to compliance and design context-specific interventions	– Promote integrated data platforms for outbreak detection and targeted interventions