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Prevention of post-weaning diarrhoea in intensive pig production: insights from the European Union project AVANT

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Summary

Post-weaning diarrhoea (PWD) is a major driver of antimicrobial use (AMU) in European pig production. The European Union's 2020–2025 multi-actor project Alternatives to Veterinary Antimicrobials, known as AVANT, evaluated various strategies to prevent PWD, including faecal filtrate transplantation (FFT), bacteriophage cocktails, immunostimulants, feed additives and fibre-based nutritional interventions. Field trials demonstrated that FFT and dietary inclusion of 5% alfalfa can reduce AMU at farm level by 21% and 6%, respectively. However, extrapolated to EU scale, these strategies would lower total livestock AMU by just 1.9% (FFT) and 0.5% (alfalfa) by 2035, far below the EU target of 50% reduction by 2030.

The project's findings indicate that no single alternative can substantially reduce AMU for PWD. As PWD is closely linked to nutritional and social stressors around weaning in current pig farming practices, eliminating reliance on metaphylactic (group) treatment requires optimised feeding and management strategies that minimise weaning-related stress, support early gut microbiome development and feed intake, and enhance disease prevention. If optimal health cannot be ensured, eliminating metaphylaxis is unrealistic, as treatment remains necessary for animal welfare.

'Raised Without Antibiotics' systems show that metaphylactic AMU can be replaced by individual treatment, while concomitantly enhancing animal health and welfare. However, these systems require substantial investment in infrastructure, training and coordination of the pig production chain. Widespread adoption of production systems that minimise AMU to the lowest possible levels requires policies that encourage infrastructure investments as well as regulatory frameworks that engage consumers with standards allowing informed choices and fair market competition. This requires significant political will.

Keywords

Antimicrobial use – EU pig production – Faecal transplantation – Nutritional interventions – Piglet health and welfare – Post-weaning diarrhoea – Raised Without Antibiotics.

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Introduction

As part of the Farm to Fork strategy [1], the European Commission targets a 50% reduction of antimicrobial use (AMU) in farmed animals and aquaculture across the European Union by 2030, using 2018 as the reference year. Antimicrobial sales dropped from 118 mg/population correction unit in 2018 to 89 mg/population correction unit in 2023, roughly half of the targeted reduction [2]. However, continued progress is needed to meet the 2030 target. Coordinated action by all EU Member States is essential to reduce the wide variability in AMU between farms, production sectors and countries. Although 2023 was the first year EU countries reported species-specific AMU data for cattle, pigs, chickens and turkeys, inconsistencies in data completeness and granularity currently prevent meaningful quantitative comparisons between animal sectors [2]. In Denmark, the pig sector accounts for 84% of total veterinary AMU (equivalent to 73 tonnes of active substance), far exceeding use in cattle (9%) and poultry (2%) [3]. Similarly, in the Netherlands, antimicrobial consumption measured in defined daily doses at the national level (DDDANAT) is significantly higher in pigs (5.9 DDDANAT) than in dairy cattle (3.0 DDDANAT) and second only to veal production (8.1 DDDANAT) [4]. The high AMU in veal production may be attributed to a high risk of disease due to calf mixing, transport stress and sudden dietary changes. However, veal production is in temporal decline and is significantly outweighed by pig production in meat volume (6.4 *versus* 20.6 million tonnes) [5] and, consequently, in total AMU. Collectively, these figures underscore the central role of pig farming as a major contributor to AMU in livestock production across the European Union.

Globally, oral metaphylactic (group) administration of antimicrobials during the suckling and post-weaning periods is a common practice in pig production [6]. A recent Danish study [7] reported that weaners account for 81% of AMU in the pig sector, measured in defined animal daily doses, with 76% of this use attributed to enteric infections. Post-weaning diarrhoea (PWD) is a leading cause of treatment in this age group, together with other early post-weaning conditions such as respiratory and other systemic. Typically occurring within 1–3 weeks after weaning, PWD is associated with high morbidity and mortality. Although it is often linked to the proliferation of enterotoxigenic *Escherichia coli* (ETEC) in the small intestine, this disease is multifactorial, with key contributing factors including housing conditions, stocking density, sow's parity, and dietary composition and digestibility [8]. Antimicrobial treatment has become increasingly challenging following the EU ban on therapeutic levels of zinc oxide due to environmental concerns and potential co-selection for AMR [9] and the global initiatives to phase out colistin use [10], which should be considered a last-resort option given its renewed importance for human medicine. Both zinc oxide and colistin were traditionally used to manage PWD outbreaks, and their restriction has substantially reduced the range of therapeutic options available to veterinarians. This challenge is further compounded by rising resistance in ETEC strains to aminoglycosides and other antimicrobials commonly used as a first-line treatment [11]. The lack of effective antimicrobial alternatives, associated with the risk of selecting resistance to antimicrobials that are critically important for human medicine, raises significant concerns for both animal and public health.

To address this One Health challenge, the EU Innovation Action Alternatives to Veterinary Antimicrobials (AVANT), which was undertaken from 2020 to 2025, aimed to reduce AMU by developing and testing innovative strategies for prevention and control of PWD in intensive pig production. This multi-actor project brought together researchers from clinical and fundamental disciplines, regulatory experts, representatives from agriculture, food and animal health industries, and veterinary associations to identify effective alternatives to conventional antimicrobials for this important disease. A diverse set of strategies, including gut microbiota modulators (i.e. synbiotics and faecal transplantation), ETEC-targeted therapies (i.e. bacteriophage cocktails and polymers), immunostimulants and dietary interventions, were evaluated in preclinical studies. Among these, faecal filtrate transplantation (FFT) and fibrous diets showed the greatest promise and were subsequently tested in field trials based on their preclinical performance and feasibility for on-farm implementation, taking into account regulatory and practical constraints that limited field testing of other approaches. Notably, a synbiotic product prototype combining three lactic acid-producing bacteria as probiotics with inulin as a prebiotic demonstrated promising performance results in the preclinical studies. However, efforts to optimise the bioprocess production of these strains have revealed technological challenges, highlighting the need for further research to enable economically feasible large-scale production and application [V. Sattler *et al.*, personal communication, 2026].

This article is intentionally framed around the outcomes and experiences of the EU-funded AVANT project. Rather than providing a comprehensive review of all available interventions for PWD, it synthesises evidence generated within AVANT field trials, preclinical studies and large datasets to reflect on practical strategies for reducing AMU in intensive pig production. Accordingly, the article summarises the main outcomes of the project, with particular emphasis on the most significant findings from field trials and on the practical feasibility of implementing the selected interventions under real-world farming conditions. In addition, this technical overview underscores the association between PWD and current pig farming practices, emphasising the need to optimise the weaning transition to further reduce reliance on antimicrobials. These issues are discussed in the context of the EU's 50% reduction target for AMU in livestock by 2030, with the aim of achieving this ambitious goal without compromising animal welfare or the economic sustainability of pig production. Notably, the findings of the AVANT project are grounded in European pig production systems and may not be directly applicable to other production contexts. Furthermore, this article does not cover the full range of interventions that may contribute to reducing AMU, including selective breeding for improved disease resistance, as these strategies were not investigated within AVANT and therefore fall outside the scope of the article.

Highlights from the AVANT project

High-fibre diets in piglets

Within AVANT, fibre-based strategies targeting piglets around weaning were optimised using a dietary inclusion of 5% alfalfa (ALF) to reduce PWD and AMU. ALF (*Medicago sativa*) is a fibrous feed ingredient rich in insoluble fibre and bioactive compounds that can promote gut health, modulate the microbiota and improve digestive function in pigs, especially during the weaning period [12,13]. Based on preclinical findings, three field trials evaluating ALF-based diets were conducted in the Netherlands, Denmark and France. In the Dutch and Danish trials, feeding 5% ALF to weaned piglets significantly reduced antimicrobial treatments for PWD during the first two weeks post-weaning without negatively affecting performance. In contrast, no reduction in antimicrobial treatments and a decrease in feed efficiency were observed in the French trial, but only when ALF was not included in solid feed before weaning. Differences in management practices, including a lower weaning age in the French herd, likely contributed to these inconsistent outcomes and highlight the importance of a transition diet, particularly for piglets with an immature gut at weaning. The Danish trial showed particularly strong results, with a 23–43% reduction in PWD (depending on faecal scoring method) and a 30% reduction in AMU, achieved through the combined use of individual treatment as an alternative to group medication [14]. These findings align with earlier studies reporting 35–40% reductions in diarrhoea when ALF is included in post-weaning diets [15,16]. Overall, the AVANT trials indicate that functional fibre such as ALF is a safe and practical tool to support gut health and reduce AMU around weaning.

Faecal filtrate transplantation in newborn piglets

An on-farm protocol was developed using faecal material from clinically healthy sows within the same herd to avoid the risk of pathogen transmission across farms. Donor material was microbiologically screened for common pig pathogens prior to filtration. Filtration was applied to remove bacterial cells; however, the virome and bacteriophage content of the filtrate was not specifically assessed in this study. FFT, in which bacteria are removed by filtration, showed gut-protective effects against PWD when administered to newborn piglets [17]. In a Danish field trial, 150 piglets received daily FFT for the first six days after birth, with a control group receiving a placebo. FFT reduced PWD prevalence by 20–50% and reduced mortality from 23% to 13% [18]. FFT-treated piglets also had higher body weight and lower prevalence of diarrhoea during suckling, although no growth differences were observed post-weaning. Microbiome analyses demonstrated persistent changes in community structure, including enrichment of beneficial bacterial families, lasting at least two weeks after weaning [18]. Although various faecal transplantation methods have been investigated in pigs [19], this represents the first trial demonstrating efficacy when administered to neonatal piglets, with benefits observed after weaning. A second trial in the Netherlands involving 230 FFT piglets from 16 litters confirmed a reduction in piglets requiring antimicrobial treatment during the first five weeks after weaning (21% to 6%), primarily affecting non-enteric conditions [A. Middelkoop *et al.*, personal communication, 2026]. These findings suggest that the benefits of FFT may extend beyond PWD prevention. FFT-treated pigs were monitored until slaughter, with no adverse effects on animal health or food safety.

Practical feasibility and economic considerations

While the ALF-based diet is relatively easy to implement within current pig farming practices, FFT presents greater practical and regulatory challenges. The procedure is labour-intensive and requires careful donor selection and processing. In the Dutch trial, the FFT preparation protocol was successfully scaled up to facilitate on-farm application (Fig. 1). However, the current EU legislation prohibits the oral administration of faecal-derived products to food-producing animals [20], although research exemptions were granted for AVANT field trials. Future development of synthetic microbial communities or bacteriophages may offer legally compliant alternatives capable of reproducing the observed benefits [21].

An AVANT economic assessment estimated negligible production cost increases (<0.2%) for the ALF-based diet. In contrast, FFT increased costs by 9–11%, primarily due to small-scale processing. Furthermore, implementation of FFT remains more expensive than ETEC vaccination, which was estimated to raise production costs by less than 1% [S. Alfonso *et al.*, personal communication, 2026]. These costs are expected to decrease with scale, although regulatory barriers remain. Importantly, this economic assessment did not account for potential savings associated with improved animal health, which could further strengthen the cost-effectiveness of both interventions.

Projected impact on antimicrobial use

Using field trial data and modelling to 2035, and assuming adoption of these interventions across all pig farms, FFT was estimated to reduce AMU in EU pig production by approximately 2%, whereas ALF-based diets could potentially lead to a reduction of around 0.5% [S. Alfonso *et al.*, personal communication, 2026]. Although modest, these reductions would contribute to lowering reliance on antimicrobials. However, projections indicate that even widespread adoption of these interventions alone would be insufficient to achieve the EU target of halving AMU by 2030, underscoring the need for integrated management approaches. These estimates should be interpreted cautiously, as intervention effectiveness is highly context-dependent and the economic analyses are indicative, being based on project-internal data that have not yet undergone independent peer review.

Impact of farm management and nutrition on antimicrobial use

AVANT also analysed data from 43 commercial farms encompassing 1,353 pig batches to assess how management practices influence antimicrobial treatments for enteric disease [22]. Most batches required no antimicrobial treatment after weaning, while a small proportion received group treatment. Antimicrobial treatment rates were not associated with prolificacy or piglet numbers but were lower in farms with fewer sows at farrowing. Farms with lower zootechnical performance and lower investment in vaccination showed higher treatment rates for post-weaning diarrhoea than high-performing farms. Transitioning to a 'secure' piglet diet characterised by lower protein content, high digestibility and increased fibre reduced antimicrobial treatments for post-weaning diarrhoea by 8.2%, while targeted vaccination eliminated treatments entirely on some farms [22]. These findings demonstrate the importance of nutrition, vaccination and management in reducing AMU.

A further key factor is the ability to identify and individually treat piglets showing signs of systemic disease. Targeted individual treatment has previously been shown to reduce antimicrobial treatments at farm level by up to 35% [23]. As many cases of PWD are linked to non-infectious causes [24,25], accurate clinical assessment is essential to avoid unnecessary antimicrobial treatment. However, individual treatment requires appropriate separation of treated and untreated piglets to limit transfer of antimicrobial-resistant bacteria between pen mates [26,27].

Discussion

AVANT findings based on field trials in Denmark, France and the Netherlands, combined with data mining of a large dataset within the consortium, indicate that routine vaccination paired with high-quality feed can effectively reduce AMU for PWD treatment. These results confirm the value of vaccination and dietary strategies in PWD prevention [28]. Within this context, AVANT findings are presented as illustrative and largely confirmatory examples that align with existing evidence on antimicrobial reduction strategies in pig production, rather than as a standalone or exhaustive strategic assessment. While FFT and ALF-based diets show promise as practical tools to lower antimicrobial reliance, AVANT projections suggest that even widespread adoption of these interventions alone would be insufficient to meet the EU's goal of a 50% reduction in AMU by 2030. Despite notable reductions in AMU across the EU over the past decade [2], substantial disparities persist both between and within countries, largely due to variations in farm management and disease prevalence. Achieving the EU's 2030 reduction target will require targeted, evidence-based strategies tailored to farm-level and country-level AMU reduction. On low-use farms and in low-use countries, the focus should be on adopting advanced tools such as precision diagnostics and alternative treatments (e.g. individual therapy), while higher-use farms and countries need outreach and tailored interventions to improve vaccination, nutrition, husbandry and biosecurity, all practices already in place on more efficient farms. However, substantial differences in production systems, feeding practices, weaning age, genetic background, and cultural and regulatory contexts may limit the transferability of individual measures, reinforcing the need for broader changes in production systems to eliminate routine AMU.

Weaning is a critical and stressful period for piglets raised under standard production as it involves early separation from the sow, a rapid shift from milk and creep feed to a plant-based solid feed only, and often moving to a new environment and mixing with unfamiliar piglets from other litters. This abrupt transition creates nutritional, environmental and social stress, increasing vulnerability to PWD and other diseases, thereby driving AMU.

In pigs, the sudden dietary shift leads to distinct gut microbiome and metabolic changes, underscoring how diet and environment shape host health [29]. Compared to wild boars, which undergo a gradual dietary transition over 6–12 weeks [30], domesticated pigs are weaned at 28 days of age or even up to a week earlier if specific conditions are met [31]. This contrast highlights the role of a more gradual transition in supporting gut maturation and adaptation to plant-based diets.

Key strategies to optimise the weaning transition

Optimising the weaning transition is complex and influenced by multiple factors inherent to modern pig production. This article identifies three key strategies to optimise the weaning transition: i) minimising weaning-related stress, ii) optimising early gut microbiome development and feed intake, and iii) preventing infection. The following sections outline measures addressing these factors, noting that farm-specific conditions may require additional tailored interventions.

Reducing weaning-related stress

States of abrupt changes for the pig, often referred to as 'stress', can lead to compromised intestinal functions [32,33] and agonistic behaviours. These may lead to depression, further reducing feed consumption, particularly when stressors include pain from skin injuries or bacterial infections following mingling and mixing [34]. The primary goal is to reduce the weaning-related stressors and associated negative consequences for piglet health and welfare. An insufficient feed intake in newly weaned piglets due to nutritional stress can compromise intestinal integrity [32,35], hinder intestinal development [36] and raise gastrointestinal pH by reducing organic acid content, thereby promoting the proliferation of enteropathogenic bacteria [37]. Hyperthermia can cause piglets to become inactive [38], while hypothermia triggers energy conservation mechanisms, reducing activity and, consequently, feed intake. To mitigate this, maintaining an ambient temperature of 26–28°C around weaning is recommended to reduce environmental stress [8]. For example, lower temperatures encourage rooting behaviour, but if piglets are unable to express this behaviour in a concrete environment, frustration can manifest as aggression towards pen mates [39,40]. Preventing such damaging interactions is crucial to reducing health risks [28,41]. Finally, hydration plays a vital role in maintaining feed intake. Water consumption is directly correlated with feeding behaviour, making both the physiological need for water and the piglet's ability to drink essential considerations [42].

Optimising early gut microbiome development and feed intake

Promoting early gut microbiome development is critical and can be achieved by stimulating dry matter intake before weaning and gradually introducing a plant-based diet while avoiding abrupt dietary changes [43]. The goal is to accelerate adaptation to plant-based ingredients in the pre-weaning phase to support sustainable growth and prevent gut microbiome dysbiosis in the post-weaning period. The most gradual dietary transition at weaning, represented by high feed intake levels after weaning, can be achieved using a transition diet at weaning, in which the same diet is fed before and after weaning [44]. This ensures that the gastro-intestinal tract of the piglets is already adapted to the post-weaning diet, preventing exposure to new feed ingredients at weaning. Moreover, the use of a transition diet also ensures that piglets recognise the diet and its characteristics, such as texture and smell. However, approximately 40% of piglets consume no solid feed or only small amounts before being weaned [45], which still puts them at risk for an abrupt nutritional change at weaning. It is therefore important to stimulate the dry matter intake of piglets before weaning, and particularly the intake of the transition diet towards weaning, because of the known correlation between pre- and post-weaning feed intake when the same diet is fed around weaning [46]. Although nutritional strategies like smell, pellet size and pellet hardness are known to affect the palatability of the pre-weaning diet, the number of eaters and their solid feed intake can also be largely stimulated by non-nutritional strategies, including feeder design and feed presentation [45].

Optimised nutritional conditions can also be supported by an increased weaning age, which allows the intestine more time to adapt to solid feed digestion and reduces the occurrence of non-eaters at weaning [47]. A five-week weaning age is probably the highest practical weaning age in modern housing systems [47,48]. However, achieving this in practice is challenging due to the widespread use of hyper-prolific sows. Extending the weaning age, and thereby lactation days, would require more farrowing pens or fewer yearly sows in each herd. Therefore, prioritising the breeding of less prolific sows – despite potential reductions in litter size and overall productivity – may be necessary to ensure better colostrum availability, improved piglet health and more sustainable production systems. Although changes in weaning age or litter size may have substantial economic implications, these aspects were not quantitatively assessed within AVANT, as such structural interventions were not experimentally evaluated in the project.

Preventing infection

Due to the epitheliochorial nature of the porcine placenta, which prevents direct antibody transfer in utero [49], colostrum intake is crucial for piglet immunity after birth [50,51]. The half-life of maternally derived antibodies in piglets ranges from approximately 9 to 14 days [52,53], meaning the duration of immune protection is directly linked to the amount of colostrum consumed at birth. Since sows typically produce a limited amount of colostrum (up to 7 kg [54]) and each piglet requires at least 200–300 g to ensure adequate immunity and energy intake, increasing litter sizes dilutes the antibody concentration per piglet, thereby reducing the duration of passive immunity. To optimise antibody transfer and neonatal protection, litter sizes should ideally be reduced to 12–14 piglets. This adjustment would increase individual colostrum intake by 25–35% compared to litters with 18.5 liveborn piglets. Additional strategies, such as split suckling and manual colostrum allocation, can, with correct adaptation, enhance passive immunity.

In summary, four key factors help prevent infection: i) reducing pathogen exposure, ii) proper sow immunisation, iii) sufficient colostrum intake, and iv) early immune stimulation via piglet vaccines. While the latter three factors enhance piglet immunity, the first focuses on minimising pathogen presence within the herd. Effective internal biosecurity is therefore essential to limit pathogen circulation and transmission. The endemic circulation of Influenza A virus (IAV) in pig production exemplifies inadequate internal biosecurity in current management systems [55,56]. In Norway, following the introduction of H1N1pdm09 in 2009, serological detection rates have declined relative to countries with endemic IAV. Smaller herd sizes and five to seven weeks of batch-based management have likely contributed to eliminating respiratory pathogens between batches. This approach is challenging in larger herds but emphasises the importance of strict sectioned batch management and microbial reduction between batches, for example by using detergents in the hygiene protocol. Major pathogens affecting piglets at weaning include ETEC, verotoxigenic *E. coli*, *Streptococcus suis*, IAV, rotavirus A and the so-called porcine respiratory disease complex, which includes both bacterial (*Pasteurella multocida*, *Actinobacillus pleuropneumoniae* and *Bordetella bronchiseptica*) and viral (porcine respirovirus 1, porcine circovirus, and porcine reproductive and respiratory syndrome virus) pathogens. Limited vaccine availability, combined with the waning of maternally derived antibodies, particularly against ETEC and IAV, heightens piglets' susceptibility after weaning. This underscores the importance of administering a pre-farrowing booster to sows to enhance antibody titres and prolong passive protection.

In the future, the development of affordable and effective vaccines would be desirable to further strengthen piglet immunity after weaning.

'Raised Without Antibiotics' systems as models for reducing antimicrobial use in pig production

Raised Without Antibiotics (RWA) farms are typically conventional operations that adopt stricter management practices to minimise disease risks rather than systems that entirely exclude antimicrobial treatment. RWA systems have proven to be effective in reducing AMU without compromising animal health and welfare. The reduced AMU in RWA production is attributed not only to improved management and thereby a decreased incidence of disease but also to the systematic use of individual antimicrobial treatment instead of metaphylaxis. Individual treatment allows for the careful selection of piglets that truly need antimicrobial treatment based on clinical indicators of systemic illness (e.g. fever, lethargy), rather than treating entire groups irrespective of health status. This approach reduces unnecessary AMU and helps preserve the gut microbiota of healthy piglets, which is particularly important during the weaning period. Individual antimicrobial treatment is therefore a defining feature of RWA systems implemented in countries such as Denmark and France, which build on best practices in modern pig farming by emphasising biosecurity, balanced nutrition and preventive health. Piglets requiring antimicrobial therapy are treated appropriately and diverted to conventional supply chains, maintaining certification integrity and animal welfare. For example, a Danish pilot project reported reductions of 75% in weaners and 66% in finishers compared with conventional farms, without an increased incidence of post-weaning diarrhoea [J.P. Nielsen *et al.*, personal communication, 2026]. However, a higher occurrence of conditions such as umbilical hernias, arthritis and pre-weaning diarrhoea was observed, likely reflecting the discontinuation of routine prophylactic treatments in neonates and highlighting the ethical challenge of balancing reduced AMU with potential health impacts on vulnerable animals.

RWA schemes differ across countries in how they define eligibility, reward farmers and integrate individual treatment into routine management. These differences may influence both adoption rates and economic sustainability. For example, RWA production has reached a higher market penetration in France than in Denmark, where limited profitability ultimately led to programme discontinuation. Such outcomes highlight the importance of aligning incentives, supply chain organisation and communication of added value to consumers. Adopting RWA production requires significant investments in training, infrastructure and operational changes. Farmers must be skilled in disease prevention and individual animal care, and facilities may require upgrades to improve ventilation, hygiene and animal welfare. RWA systems also require more intensive health monitoring and stricter biosecurity, increasing labour and management burdens. These long-term investments must be justified through viable business models, which can be challenging under volatile market conditions.

There is evidence that with proper coaching, pig farmers can successfully adopt and sustain RWA production. A Belgian study [57] showed that approximately half of participating herds transitioned to RWA within one year, with most maintaining this status thereafter. RWA farms tended to be smaller and more frequently applied batch-farrowing systems, while differences in weaning age were modest. These findings suggest that successful RWA implementation depends on a combination of pre-existing herd characteristics and management adjustments, although data remain limited to a small number of countries.

RWA labelling is often used to communicate reduced exposure to antimicrobials employing claims such as 'no antibiotics for growth promotion' or 'no antibiotics in the last 150 days' [58]. While more informative than symbolic labels, such claims provide limited insight into the scale or purpose of AMU. This underscores the need for clearer and more standardised terminology that reflects meaningful differences in AMU practices. Credibility is central to any food labelling system, and third-party verification may be required to maintain consumer trust, particularly during early implementation phases [59,60]. However, consumer awareness of reduced AMU does not always translate into purchasing behaviour, highlighting the persistent intention–behaviour gap observed in other sustainability domains [61,62].

Future perspectives

The AVANT interventions, such as the ALF-based diet and FFT, show promise for reducing PWD-related AMU, but minimising AMU to the lowest feasible levels will require widespread adoption of integrated production systems that combine tailored feeding, improved management, enhanced biosecurity and effective disease prevention, such as RWA. While comprehensive cost data on RWA systems remain limited, retail prices for RWA products appear to be significantly higher than those of conventional products, with the price gap largely exceeding differences in production costs.

Shifting from reactive to proactive policies is essential to establish sustainable, One Health-driven food systems that prioritise human, animal and environmental health over market prices [63]. Proactive measures address root causes of issues like antibiotic resistance and environmental degradation, foster resilience, reduce long-term costs, and align with consumer demands for sustainability and transparency. By integrating One Health principles, these policies promote equitable, sustainable practices, safeguard public health and position food systems to better withstand global challenges like antibiotic resistance and climate (Fig. 2).

On the supply side, the sustainability of RWA will hinge on the ability to shift to proven RWA-geared management practices at minimal cost and to further segment meat product lines, potentially including nudges to push lower-range consumers towards higher quality and possibly smaller quantities. These could include weight norms at end sale, limiting RWA labelling to a maximum of 2–3 definitions, conversion of fresh pork to further packaged products, creation of ranges intended for flavourings sold in smaller volumes (e.g. bacon-derived) and a subsidy to cover RWA verification. A tax could theoretically be applied instead, as suggested by Price *et al.* [59]; however, these would be punitive for the very market actors ideally being encouraged towards RWA.

On the demand side, sustainability will depend on a better understanding among consumers of the full benefits to be reaped for the individual and fellow humans, for animals and for the environment – both now and in the future. Providing a clear definition of RWA production as outlined in the context of this article would improve clarity and reduce potential misinterpretations. Lessons from experiences in climate science communication will be crucial in this endeavour. Europeans would do well to establish a clear strategy for such communication *ex ante* within the overall sustainability policy. Again, this would need to be underpinned by a credible and understandable labelling system with information clearly available at the point of sale. Finally, contextualised market research would be needed to better understand the shape and magnitude of the intention–behaviour gap as it applies to this specific question, again focusing on demonstrated purchase patterns rather than stated levels of willingness to pay for theoretical products in a theoretical financial context, including opportunity costs.

Conclusions

Effective PWD prevention relies on targeted diets and optimal farm management practices to protect piglet health and welfare during the weaning transition. Since PWD is closely linked to the stress experienced during weaning in intensive systems, eliminating routine AMU requires at least three key strategies to optimise the weaning transition: i) minimising weaning-related stress, ii) optimising early gut microbiome development and feed intake, and iii) preventing infection. Implementing these measures across the EU demands coordinated action along the production chain and among Member States. Where such conditions are not met, AMU remains necessary to safeguard animal welfare.

In this context, RWA is used to describe currently feasible production systems that minimise AMU through preventive management, enhanced biosecurity and targeted individual treatment rather than an absolute or guaranteed antibiotic-free status for all pigs. RWA pig production can represent a viable and sustainable strategy to reduce AMU while supporting animal welfare and meeting consumer expectations. However, its long-term success depends on ensuring that animal health is not compromised, which requires careful implementation and further research. Promoting well-defined systems like RWA could help achieve the EU Farm to Fork Strategy's goal of halving antimicrobial sales for livestock by 2030, provided that animal health and economic viability are safeguarded. RWA may also contribute to reducing pig farming's environmental footprint. Experiences from France and Denmark show that RWA is technically feasible, but success depends on shared commitment across the pig value chain. Fair distribution of implementation costs, standardised definitions and regulatory support, including enforcement of the reciprocity principle in EU veterinary medicinal law to prevent import of lower-standard pig meat from third countries, are all essential. Broad adoption will also require active involvement of processors and retailers, supported by targeted public investment in infrastructure, farmer training and preventive veterinary medicine. Achieving such a transition will require strong political will and coordinated institutional support. A One Health approach that integrates behavioural and systemic change is key to reshaping food systems for better public health, animal welfare and environmental sustainability.

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Prévention de la diarrhée post-sevrage des porcelets dans les élevages porcins intensifs : la perspective du projet AVANT de l'Union européenne

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Résumé

En Europe, l'une des principales causes d'utilisation des antimicrobiens (UAM) en production porcine est la diarrhée post-sevrage. Dans ce contexte, le projet multi-acteurs de l'Union européenne pour la période 2020-2025 intitulé « Alternatives aux antimicrobiens vétérinaires », dénommé AVANT, a évalué diverses stratégies de prévention de la diarrhée post-sevrage, notamment la transplantation de filtrat fécal, les cocktails de bactériophages, les immunostimulants, les additifs alimentaires et les interventions nutritionnelles à base de fibres. Des essais sur le terrain ont montré que la transplantation de filtrat fécal et l'incorporation de 5 % de luzerne dans l'alimentation se traduisent par une réduction de l'UAM dans les élevages pouvant atteindre respectivement 21 % et 6 %. Toutefois, extrapolées à l'échelle de l'UE, ces stratégies ne feraient baisser l'UAM totale dans le secteur de l'élevage que de 1,9 % (pour la transplantation de filtrat fécal) et de 0,5 % (pour la luzerne) d'ici 2035, ce qui est bien en deçà de l'objectif européen de réduction de 50 % d'ici 2030.

Les résultats du projet indiquent qu'aucune alternative unique ne permet à elle seule de réduire substantiellement l'UAM liée à la diarrhée post-sevrage. La diarrhée des porcelets sevrés étant étroitement liée aux stress nutritionnels et sociaux induits par le sevrage dans les pratiques modernes d'élevage porcin, il ne sera possible de se passer de traitements métaphylactiques (collectifs) qu'en mettant en place des stratégies d'alimentation et de gestion optimisées visant à minimiser le stress lié au sevrage, à favoriser le développement précoce du microbiome intestinal et la prise alimentaire, et à renforcer la prévention des maladies. Si un état de santé optimal des porcelets ne peut être garanti par ces moyens, la suppression de la métaphylaxie est une option irréaliste car le traitement reste un impératif de bien-être animal.

Les systèmes « Élevé sans antibiotiques » montrent que l’utilisation métaphylactique d’antimicrobiens peut être remplacée par des traitements à l’échelle de l’individu, accompagnés d’une amélioration globale de la santé et du bien-être des animaux. Ces systèmes requièrent toutefois des investissements importants en infrastructures, des efforts de formation et une bonne coordination de la filière porcine. L’adoption généralisée de systèmes de production visant à réduire l’UAM au niveau le plus bas possible nécessite des politiques favorisant les investissements d’infrastructure, ainsi que des cadres réglementaires pour mobiliser les consommateurs grâce à des normes permettant des choix éclairés et une concurrence loyale sur le marché. Ces mesures exigent une forte volonté politique.

Mots-clés

Diarrhée post-sevrage des porcelets – Élevé sans antibiotiques – Interventions nutritionnelles – Production porcine dans l’UE – Santé et bien-être des porcelets – Transplantation fécale – Utilisation des antimicrobiens.

Prevención de la diarrea posterior al destete en la producción porcina intensiva: conclusiones del proyecto AVANT de la Unión Europea

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Resumen

La diarrea posterior al destete es un factor determinante del uso de antimicrobianos (UAM) en la producción porcina europea. El proyecto con múltiples actores que la Unión Europea implementó entre 2020 y 2025, conocido como AVANT (Alternativas a los Antimicrobianos Veterinarios), evaluó diversas estrategias para prevenir la diarrea posterior al destete, incluyendo el trasplante de filtrado fecal (TFF), cócteles de bacteriófagos, inmunoestimulantes, aditivos para piensos e intervenciones nutricionales a base de fibra. Los ensayos de campo demostraron que el TFF y la inclusión de un 5% de alfalfa en la dieta pueden reducir el UAM en la explotación en un 21% y un 6%, respectivamente. Sin embargo, estas estrategias, extrapoladas a escala de la UE, reducirían el UAM total en la ganadería solo en un 1,9% (TFF) y un 0,5% (alfalfa) de aquí a 2035, es decir a un nivel muy inferior al objetivo de la UE de reducirlo en un 50% para 2030.

Los resultados del proyecto indican que ninguna alternativa puede reducir sustancialmente por sí sola el UAM para la diarrea posterior al destete. Teniendo en cuenta que la diarrea posterior al destete está estrechamente relacionada con factores de estrés nutricionales y sociales durante el destete en las prácticas actuales de cría de cerdos, eliminar la dependencia del tratamiento metafiláctico (grupal) requiere estrategias optimizadas de alimentación y manejo que minimicen el estrés relacionado con el destete; favorezcan el desarrollo precoz de la microbiota intestinal y la ingesta de alimento, y mejoren la prevención de enfermedades. Si no se puede garantizar una sanidad óptima, resulta poco realista eliminar la metafilaxis, ya que el tratamiento sigue siendo necesario para garantizar el bienestar animal.

Los sistemas «Cría sin antibióticos» muestran que el uso de antimicrobianos metafilácticos puede sustituirse por un tratamiento individual, mejorando simultáneamente la sanidad y el bienestar animal. Sin embargo, se trata de sistemas que requieren una inversión importante en infraestructura, formación y coordinación de la cadena de producción porcina. La adopción generalizada de sistemas de producción que reduzcan el UAM a los niveles más bajos posibles requiere la aplicación de políticas que fomenten las inversiones en infraestructura, así como marcos normativos que involucren a los consumidores con normas que permitan la toma de decisiones informadas y una competencia justa en el mercado. Todo esto implica contar con una importante voluntad política.

Palabras clave

Cría sin antibióticos – Diarrea posterior al destete – Intervenciones nutricionales – Producción porcina en la UE – Sanidad y bienestar de los lechones – Trasplante fecal – Uso de antimicrobianos.

References

[1] European Commission. Farm to fork strategy: for a fair, healthy and environmentally-friendly food system. Brussels (Belgium): European Union; 2020. 23 p. Available at: https://food.ec.europa.eu/system/files/2020-05/f2f_action-plan_2020_strategy-info_en.pdf (accessed on 2 March 2026).

[2] European Medicines Agency. European sales and use of antimicrobials for veterinary medicine: annual surveillance report for 2023. Luxembourg: Publications Office of the European Union; 2025. 106 p. Available at: https://www.ema.europa.eu/en/documents/report/european-sales-use-antimicrobials-veterinary-medicine-annual-surveillance-report-2023_en.pdf (accessed on 3 March 2026).

[3] The Netherlands Veterinary Medicines Institute. Usage of antibiotics in agricultural livestock in the Netherlands in 2023: trends and benchmarking of livestock farms and veterinarians. Utrecht (The Netherlands): The Netherlands Veterinary Medicines Institute; 2024. 71 p. Available at: https://cdn.i-pulse.nl/autoriteitdiergeneesmiddelen/userfiles/sda%20jaarrapporten%20ab-gebruik/AB-rapport%202023/sda-rapport-incl.-cover-letter---usage-of-antibiotics-livestock-in-the-netherlands-in-2023-def.pdf (accessed on 3 March 2026).

[4] Ribeiro Duarte AS, Pessoa J, Attauabi M, Lindegaard M, Wolff Sönksen U, eds. DANMAP 2023: use of antimicrobial agents and occurrence of antimicrobial resistance in bacteria from food animals, food and humans in Denmark. Copenhagen (Denmark): Statens Serum Institut, National Food Institute, Technical University of Denmark; 2024. 190 p. Available at: https://www.danmap.org/reports/2023 (accessed on 3 March 2026).

[5] Agricultural production: livestock and meat. Luxembourg: Eurostat; 2025. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agricultural_production_-_livestock_and_meat (accessed on 3 March 2026).

[6] Lekagul A, Tangcharoensathien V, Yeung S. Patterns of antibiotic use in global pig production: a systematic review. Vet. Anim. Sci. 2019;7:100058. https://doi.org/10.1016/j.vas.2019.100058

[7] Moura P, Sandberg M, Høg BB, Niza-Ribeiro J, Nielsen EO, Alban L. Characterisation of antimicrobial usage in Danish pigs in 2020. Front. Vet. Sci. 2023;10:1155811. https://doi.org/10.3389/fvets.2023.1155811

[8] Rhouma M, Fairbrother JM, Beaudry F, Letellier A. Post weaning diarrhea in pigs: risk factors and non-colistin-based control strategies. Acta Vet. Scand. 2017;59(1):31. https://doi.org/10.1186/s13028-017-0299-7

[9] European Commission (EC). Commission implementing decision concerning, in the framework of Article 35 of Directive 2001/82/EC of the European Parliament and of the Council, the marketing authorisations for veterinary medicinal products containing "zinc oxide" to be administered orally to food producing species. Brussels (Belgium): EC; 2017. 3 p. Available at: https://ec.europa.eu/health/documents/community-register/2017/20170626136754/dec_136754_en.pdf (accessed on 3 March 2026).

[10] Ahmed MO, Abouzeed YM, Daw MA. Global initiatives to phase-out colistin use in food-producing animals. Open Vet. J. 2025;15(2):533-40. https://doi.org/10.5455/OVJ.2025.v15.i2.4

[11] Subramani P, Pirolo M, Haugegaard S, Skarbye AP, Conrady B, Pedersen KS, *et al*. Neomycin resistance in clinical *Escherichia coli* from Danish weaner pigs is associated with recent neomycin use and presence of F4 or F18 fimbriaes. Prev. Vet. Med. 2023;212:105852. https://doi.org/10.1016/j.prevetmed.2023.105852

[12] Wang J, Qin C, He T, Qiu K, Sun W, Zhang X, *et al*. Alfalfa-containing diets alter luminal microbiota structure and short chain fatty acid sensing in the caecal mucosa of pigs. J. Anim. Sci. Biotechnol. 2018;9:11. https://doi.org/10.1186/s40104-017-0216-y

[13] Ma J, Huangfu W, Yang X, Xu J, Zhang Y, Wang Z, *et al.* "King of the forage" – alfalfa supplementation improves growth, reproductive performance, health condition and meat quality of pigs. Front. Vet. Sci. 2022;9:1025942. https://doi.org/10.3389/fvets.2022.1025942

[14] Hansen SV, Sørensen G, Boldsen SK, Nielsen JP. Dietary inclusion of alfalfa reduces treatment-requiring diarrhea in weaned pigs. Animal. 2026;(in press).

[15] Adams S, Xiangjie K, Hailong J, Guixin Q, Sossah FL, Dongsheng C. Prebiotic effects of alfalfa (*Medicago sativa*) fiber on cecal bacterial composition, short-chain fatty acids, and diarrhea incidence in weaning piglets. RSC Adv. 2019;9(24):13586-99. https://doi.org/10.1039/C9RA01251F

[16] Liu B, Wang W, Zhu X, Sun X, Xiao J, Li D, *et al*. Response of gut microbiota to dietary fiber and metabolic interaction with SCFAs in piglets. Front. Microbiol. 2018;9:2344. https://doi.org/10.3389/fmicb.2018.02344

[17] Larsen C, Andersen AB, Sato H, Brunse A, Thymann T. Transplantation of fecal filtrate to neonatal pigs reduces post-weaning diarrhea: a pilot study. Front. Vet. Sci. 2023;10:1110128. https://doi.org/10.3389/fvets.2023.1110128

[18] Larsen C, Pirolo M, Rasmussen TS, Brunse A, Mikkelsen CV, Haugaard MM, *et al*. Faecal filtrate transplantation in neonatal pigs induces gut microbiota changes and reduces mortality and diarrhoea. Gut. Microbiol. 2026;(in press).

[19] Canibe N, O'Dea M, Abraham S. Potential relevance of pig gut content transplantation for production and research. J. Anim. Sci. Biotechnol. 2019;10:55. https://doi.org/10.1186/s40104-019-0363-4

[20] Brunner R, Straube J, Richter S, Huettinger C, Gambino M, Thymann T, *et al*. AVANT: developing alternatives to veterinary antimicrobials in the European Union regulatory context. Rev. Sci. Tech. 2025;44:3736. https://doi.org/10.20506/rst.44.3736

[21] Brunse A, Deng L, Pan X, Hui Y, Castro-Mejía JL, Kot W, *et al*. Fecal filtrate transplantation protects against necrotizing enterocolitis. ISME J. 2022;16(3):686-94. https://doi.org/10.1038/s41396-021-01107-5

[22] Buchet A, Samson V, Riera B, Gloaguen M. Effet des facteurs d'élevage et des changements de pratiques sur l'utilisation des antibiotiques à visée digestive chez le porcelet. Journées Rech. Porcine. 2025;57:279-84. Available at: https://www.journees-recherche-porcine.com/texte/2025/santeanimale/s06.pdf (accessed on 3 March 2026).

[23] Kudirkiene E, Eriksen EØ, Liu G, Christensen AE, Agerlin MV, Larsen I, *et al*. Selection of resistant coliform bacteria in the intestine of pigs following flock versus individual treatment with neomycin against post-weaning diarrhoea or amoxicillin against umbilical infection. Lett. Appl. Microbiol. 2025;78(2):ovaf008. https://doi.org/10.1093/lambio/ovaf008

[24] Weber N, Nielsen JP, Jakobsen AS, Pedersen L-L, Hansen CF, Pedersen KS. Occurrence of diarrhoea and intestinal pathogens in non-medicated nursery pigs. Acta Vet. Scand. 2015;57:64. https://doi.org/10.1186/s13028-015-0156-5

[25] Eriksen EØ, Kudirkiene E, Barington K, Goecke NB, Blirup-Plum SA, Nielsen JP, *et al*. An observational field study of porcine post-weaning diarrhea: clinical and microbiological findings, and fecal pH-measurements as a potential diagnostic tool. Porcine Health Manag. 2023;9(1):33. https://doi.org/10.1186/s40813-023-00325-x

[26] Græsbøll K, Damborg P, Mellerup A, Herrero-Fresno A, Larsen I, Holm A, *et al*. Effect of tetracycline dose and treatment mode on selection of resistant coliform bacteria in nursery pigs. Appl. Environ. Microbiol. 2017;83(12):e00538-17. https://doi.org/10.1128/aem.00538-17

[27] Tams KW, Larsen AR, Pedersen K, Ingham AC, Folkesson A, Larsen I, *et al*. Resistomes from oxytetracycline-treated pigs are readily transferred to untreated pen mates. Anim. Microbiome. 2024;6(1):70. https://doi.org/10.1186/s42523-024-00356-x

[28] Canibe N, Højberg O, Kongsted H, Vodolazska D, Lauridsen C, Nielsen TS, *et al*. Review on preventive measures to reduce post-weaning diarrhoea in piglets. Animals (Basel). 2022;12(19):2585. https://doi.org/10.3390/ani12192585

[29] Ding J, Cui X, Wang X, Zhai F, Wang L, Zhu L. Multi-omics analysis of gut microbiota and metabolites reveals contrasting profiles in domestic pigs and wild boars across urban environments. Front. Microbiol. 2024;15:1450306. https://doi.org/10.3389/fmicb.2024.1450306

[30] Van Kerschaver C, Turpin D, Michiels J, Pluske J. Reducing weaning stress in piglets by pre-weaning socialization and gradual separation from the sow: a review. Animals (Basel). 2023;13(10):1644. https://doi.org/10.3390/ani13101644

[31] Council of the European Union. Council Directive 2008/120/EC of 18 December 2008 laying down minimum standards for the protection of pigs. Off. J. Eur. Union. 2009;L 47:5-13. Available at: https://eur-lex.europa.eu/eli/dir/2008/120/oj/eng (accessed on 3 March 2026).

[32] Upadhaya S-D, Kim I-H. The impact of weaning stress on gut health and the mechanistic aspects of several feed additives contributing to improved gut health function in weanling piglets – a review. Animals (Basel). 2021;11(8):2418. https://doi.org/10.3390/ani11082418

[33] Tang X, Xiong K, Fang R, Li M. Weaning stress and intestinal health of piglets: a review. Front. Immunol. 2022;13:1042778. https://doi.org/10.3389/fimmu.2022.1042778

[34] Hwang H-S, Lee J-K, Eom T-K, Son S-H, Hong J-K, Kim K-H, *et al*. Behavioral characteristics of weaned piglets mixed in different groups. Asian-Australas. J. Anim. Sci. 2016;29(7):1060-4. https://doi.org/10.5713/ajas.15.0734

[35] McCracken BA, Spurlock ME, Roos MA, Zuckermann FA, Gaskins HR. Weaning anorexia may contribute to local inflammation in the piglet small intestine. J. Nutr. 1999;129(3):613-9. https://doi.org/10.1093/jn/129.3.613

[36] Fabà L, Hulshof TG, Venrooij KCM, Van Hees HMJ. Variability in feed intake the first days following weaning impacts gastrointestinal tract development, feeding patterns, and growth performance in nursery pigs. J. Anim. Sci. 2024;102:skad419. https://doi.org/10.1093/jas/skad419

[37] Connolly KR, Sweeney T, O'Doherty JV. Sustainable nutritional strategies for gut health in weaned pigs: the role of reduced dietary crude protein, organic acids and butyrate production. Animals (Basel). 2025;15(1):66. https://doi.org/10.3390/ani15010066

[38] Hart BL. Biological basis of the behavior of sick animals. Neurosci. Biobehav. Rev. 1988;12(2):123-37. https://doi.org/10.1016/s0149-7634(88)80004-6

[39] Olczak K, Nowicki J, Klocek C. Pig behaviour in relation to weather conditions – a review. Ann. Anim. Sci. 2015;15(3):601-10. https://doi.org/10.1515/aoas-2015-0024

[40] Winters JFM, Kobek-Kjeldager C, Foldager L, Tecles F, Pedersen LJ. Stress responses in pigs postweaning: effect of heavier hybrid and weaning intact litters. Appl. Anim. Behav. Sci. 2023;269:106106. https://doi.org/10.1016/j.applanim.2023.106106

[41] Boyle LA, Edwards SA, Bolhuis JE, Pol F, Šemrov MZ, Schütze S, *et al*. The evidence for a causal link between disease and damaging behavior in pigs. Front. Vet. Sci. 2021;8:771682. https://doi.org/10.3389/fvets.2021.771682

[42] Dybkjær L, Jacobsen AP, Tøgersen FA, Poulsen HD. Eating and drinking activity of newly weaned piglets: effects of individual characteristics, social mixing, and addition of extra zinc to the feed. J. Anim. Sci. 2006;84(3):702-11. https://doi.org/10.2527/2006.843702x

[43] Choudhury R, Middelkoop A, Boekhorst J, Gerrits WJJ, Kemp B, Bolhuis JE, *et al*. Early life feeding accelerates gut microbiome maturation and suppresses acute post-weaning stress in piglets. Environ. Microbiol. 2021;23(11):7201-13. https://doi.org/10.1111/1462-2920.15791

[44] Huting AMS, Middelkoop A, Guan X, Molist F. Using nutritional strategies to shape the gastro-intestinal tracts of suckling and weaned piglets. Animals (Basel). 2021;11(2):402. https://doi.org/10.3390/ani11020402

[45] Middelkoop A, Choudhury R, Gerrits WJJ, Kemp B, Kleerebezem M, Bolhuis JE. Effects of creep feed provision on behavior and performance of piglets around weaning. Front. Vet. Sci. 2020;7:520035. https://doi.org/10.3389/fvets.2020.520035

[46] Kuller WI, Soede NM, van Beers-Schreurs HMG, Langendijk P, Taverne MAM, Verheijden JHM, *et al*. Intermittent suckling: effects on piglet and sow performance before and after weaning. J. Anim. Sci. 2004;82(2):405-13. https://doi.org/10.2527/2004.822405x

[47] Al Masri S, Hünigen H, Al Aiyan A, Rieger J, Zentek J, Richardson K, *et al*. Influence of age at weaning and feeding regimes on the postnatal morphology of the porcine small intestine. J. Swine Health Prod. 2015;23(4):186-203. https://doi.org/10.54846/jshap/875

[48] Moeser AJ, Pohl CS, Rajput M. Weaning stress and gastrointestinal barrier development: implications for lifelong gut health in pigs. Anim. Nutr. 2017;3(4):313-21. https://doi.org/10.1016/j.aninu.2017.06.003

[49] Carter AM, Enders AC. The evolution of epitheliochorial placentation. Annu. Rev. Anim. Biosci. 2013;1:443-67. https://doi.org/10.1146/annurev-animal-031412-103653

[50] Devillers N, Le Dividich J, Prunier A. Influence of colostrum intake on piglet survival and immunity. Animal. 2011;5(10):1605-12. https://doi.org/10.1017/s175173111100067x

[51] Quesnel H, Farmer C, Devillers N. Colostrum intake: influence on piglet performance and factors of variation. Livest. Sci. 2012;146(2-3):105-14. https://doi.org/10.1016/j.livsci.2012.03.010

[52] Frenyó VL, Pethes G, Antal T, Szabó I. Changes in colostral and serum IgG content in swine in relation to time. Vet. Res. Commun. 1980;4(4):275-82. https://doi.org/10.1007/BF02278503

[53] Polo J, Campbell JM, Crenshaw J, Rodríguez C, Pujol N, Navarro N, *et al*. Half-life of porcine antibodies absorbed from a colostrum supplement containing porcine immunoglobulins. J. Anim. Sci. 2012;90(Suppl. 4):308-10. https://doi.org/10.2527/jas.53716

[54] Nuntapaitoon M, Juthamanee P, Theil PK, Tummaruk P. Impact of sow parity on yield and composition of colostrum and milk in Danish Landrace × Yorkshire crossbred sows. Prev. Vet. Med. 2020;181:105085. https://doi.org/10.1016/j.prevetmed.2020.105085

[55] Ryt-Hansen P, Krog JS, Breum SØ, Hjulsager CK, Pedersen AG, Trebbien R, *et al*. Co-circulation of multiple influenza A reassortants in swine harboring genes from seasonal human and swine influenza viruses. eLife. 2021;10:e60940. https://doi.org/10.7554/elife.60940

[56] Goel V, Ding J, Hatuwal B, Giri E, Deliberto TJ, Lowe J, *et al*. Ecological drivers of evolution of swine influenza in the United States: a review. Emerg. Microbes Infect. 2025;14(1):2455598. https://doi.org/10.1080/22221751.2025.2455598

[57] Bernaerdt E, Maes D, Van Limbergen T, Postma M, Dewulf J. Determining the characteristics of farms that raise pigs without antibiotics. Animals (Basel). 2022;12(10):1224. https://doi.org/10.3390/ani12101224

[58] United States Department of Agriculture (USDA) Food Safety and Inspection Service. Animal raising claims labeling guidelines update. Washington DC (United States of America): USDA; 2021. 45 p. Available at: https://www.fsis.usda.gov/sites/default/files/media_file/2021-09/Animal- Raising-Claims-labeling-and-Non-GMO-slides-2021-09-01.pdf (accessed on 2 March 2026).

[59] Price LB, Rogers L, Lo K. Policy reforms for antibiotic use claims in livestock. Science. 2022;376(6589):130-2. https://doi.org/10.1126/science.abj1823

[60] Bowman M, Marshall KK, Kuchler F, Lynch L. Raised without antibiotics: lessons from voluntary labeling of antibiotic use practices in the broiler industry. Am. J. Agric. Econ. 2016;98(2):622-42. https://doi.org/10.1093/ajae/aaw008

[61] Gleim M, Lawson SJ. Spanning the gap: an examination of the factors leading to the green gap. J. Consum. Mark. 2014;31(6-7):503-14. https://doi.org/10.1108/JCM-05-2014-0988

[62] Ancillotti M, Nihlén Fahlquist J, Eriksson S. Individual moral responsibility for antibiotic resistance. Bioethics. 2022;36(1):3-9. https://doi.org/10.1111/bioe.12958

[63] Rushton J, McMahon BJ, Wilson ME, Mazet JAK, Shankar B. A food system paradigm shift: from cheap food at any cost to food within a One Health framework. NAM Perspect. 2021;202111b. https://doi.org/10.31478/202111b

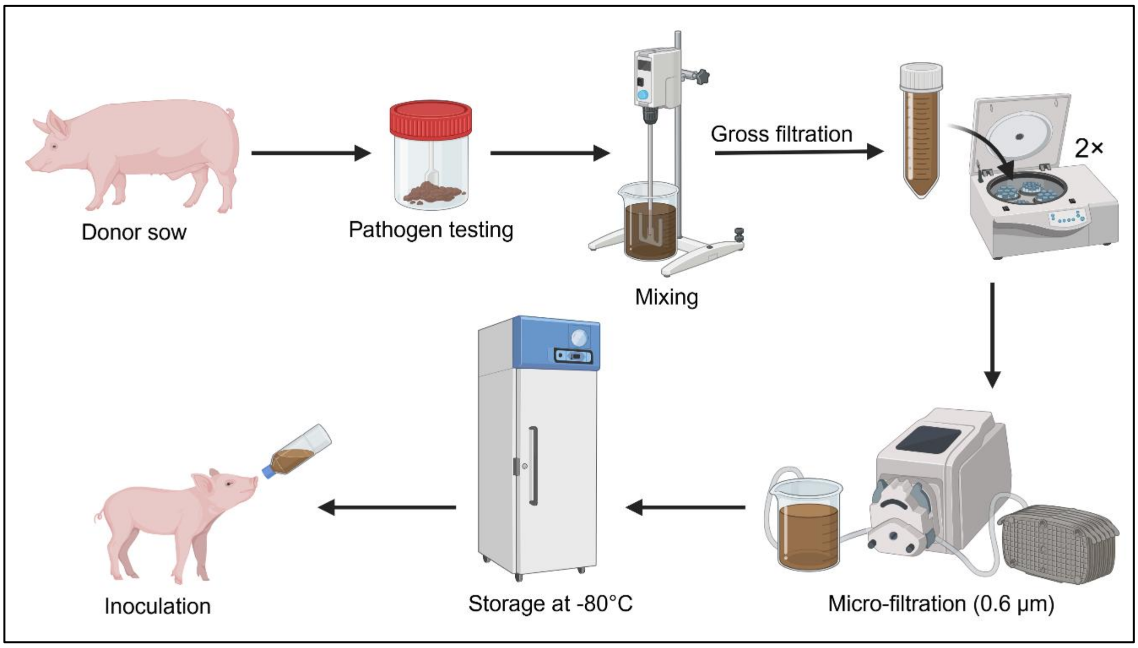

Figure 1

Schematic overview of the on-farm protocol for donor selection and preparation of faecal filtrate transplant for administration to newborn piglets

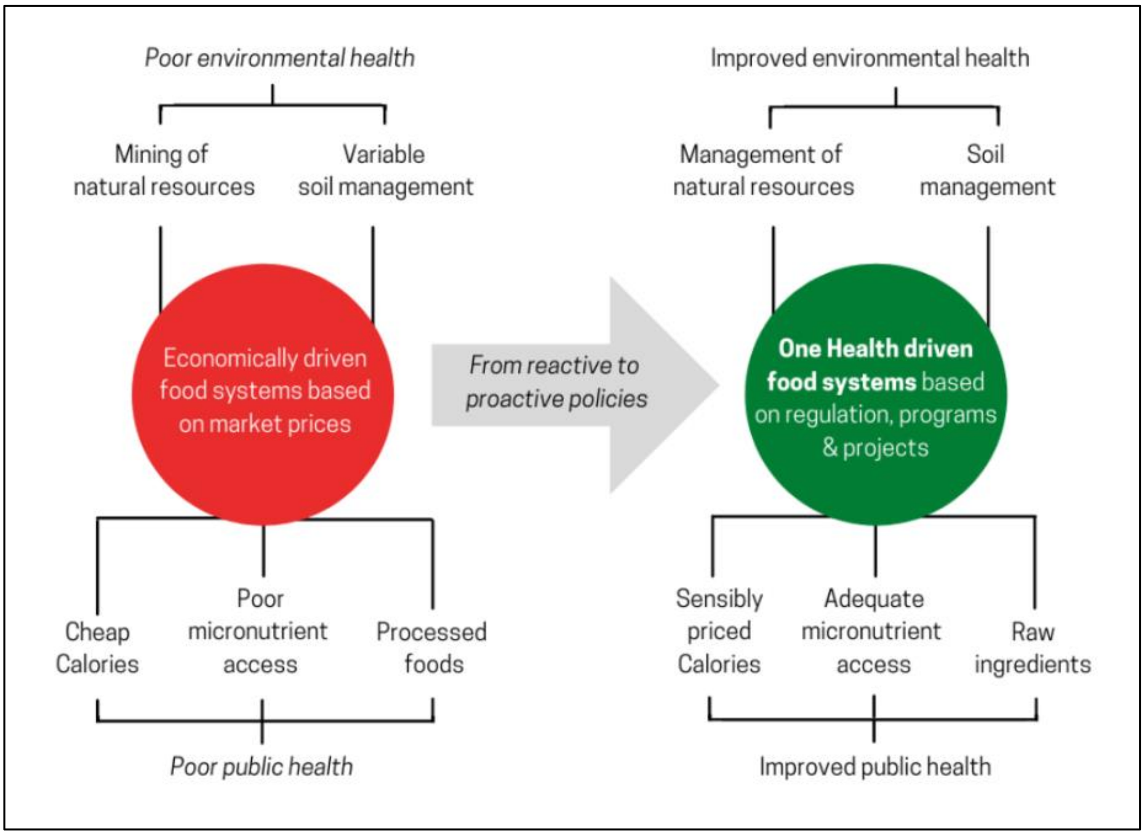

Figure 2

Paradigm shift from economically driven to One Health-driven food systems (from [63])