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Research Article

Costs and Benefits of Innovations able to Reduce the use of Antimicrobials on Pig and Broiler Farms

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Abstract

Many pig and broiler farmers struggle to reduce the use of antimicrobials on their farms. The improvement of the level of biosecurity certainly is one of the most effective ways to prevent pathogens entering the farm. Research is focused however also on other strategies, which may reduce the reliance on antimicrobials: increase animals' resilience, early detection of diseases and targeted use of antimicrobials. These three strategies may exert a long term effect on the necessity tofight animal diseases. Several innovations are being tested that belong to these strategies, but most of these techniques have not yet been applied at farm scale In this paper a first analysis has been carried out to estimate the costs and benefits of innovations to improve resilience, to early detect diseases and to implement a targeted use of antimicrobials. As most of the innovations have been tested in experimental settings, the results of the economic analysis still have be treated with care. It provides however a first assessment of the economic convenience of the innovations and a list of key performance indicators that need to be taken into account in the analysis. For this analysis the partial budgeting approach has been used. Where broilers are concerned the analysis has been centred on on-farm hatching, elevated platforms, use of probiotics, automatic weighing systems and targeted use of non-antimicrobial feed and/or water additives. For pigs the analysis has been focused on innovative enrichment material to improve pig welfare and video-surveillance systems to early detect diseases.

Keywords: Antimicrobials; Animal Resilience; Early Detection; Economics; Innovations; Targeted use

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Introduction

In order to reduce the use of antimicrobials a series of innovations in pig and broiler farms may be implemented. Some of these innovative techniques are mature, but are not yet fully implemented because they are not well known by the majority of farmers and others are still currently being tested in order to assess their efficacy in reducing the recourse to antimicrobials on farm. In this paper the analysis of costs and benefits concerning innovations related to three strategies considered able to reduce the use of antimicrobials on pig and broiler farms are presented:

1. Enhancing resilience and animal welfare
2. Early detection of diseases
3. Targeted use of antimicrobials

A fourth important strategy to reduce the use of antimicrobials on poultry and pig farms is the implementation of biosecurity measures, but this strategy is dealt with in another paper by de Roest et.al, 2023.

The concept of resilience, when applied to individual animals was defined as the ability of animals to cope with short-term perturbations in their environment and return rapidly to their pre-challenge status [1] or more generally the ability of animals to adapt to environmental challenges with minimal loss of function [2]. Resilience applies to the response of individuals to disease challenges, but also to environmental and social stressors, such heat stressors or overcrowding. More resilient animals are somehow better equipped to cope with challenges including (endemic) infectious challenges, thus reducing the impact of infection. More resilient animals can better cope with challenges including (endemic) infections, thus reducing the impact ofdisease and therefore expected to have a reduced need for antimicrobials. Evidence already exists that animal welfare friendly pig production systems, which enhance natural behaviour and reduce stress, resulted in increased ability to cope with mild disease challenges [3]. If animal welfare friendly production systems or specific aspects of these systems result in better health and improved resilience against disease, this would be crucial for the adoption of these systems and solutions and can contribute to the further reduction of antimicrobial use. The improvement of the resilience of animals considered in this paper relate to either nutritional improvement of the balance of gut microbiota or welfare improvements which reduce stress in early life. Stress reduction through welfare improvements of broilers can be obtained by means of on-farm hatching systems, where day old chicks have immediate access to feed and water. During conventional hatching of chicks a fasting period longer than 48 hours may increase mortality rates [4] and can have a negative impact on growth performance [5]. The chicks within this type of hatching systems can be prone to a higher susceptibility to diseases in environments with higher antigenic pressure [5]. Alternatives to conventional hatching are systems which provide light, feed and water in a hatcher (hatchery-fed) or where hatching takes place directly at the broiler farm with immediate access to feed and water (on-farm hatched). The advantage of the first alternative system is that the chicks are not exposed to a fasting period, whereas the second system adds to the previous advantage the fact that the chicks are not handled and transported anymore from the hatchery to the broiler farm. Several companies have developed alternative hatching systems able to allow higher performances and efficiency with possibly more resilient broilers at higher levels of welfare, lower mortality rates and potentially a lower susceptibility to diseases, which may finally reduce the use of antimicrobials.Another innovation related to the improvement of resilience are elevated platforms. These platforms allow broilers to improve their walking ability and reduce the present of foot pad lesions through less humid litter [6]. The improvement of the resilience of broilers may reduce their vulnerability against pathogens and diseases and will ultimately contribute to the reduction of the use of antimicrobials. The introduction of environmental enrichment and elevated platforms in broiler houses, which the chickens will use for resting, may reduce problems arising during the grower period such as heat stress and impaired walking ability.

The mere provision of environmental enrichment will cause increased activity and may have adverse effects on the performance of broilers [3]. Elevated platforms offer however additional possibilities for broilers and seem to improve gait and leg health of broilers [7,8]. The knowledge on the economic effect of a production system, i.e. whether the extra costs of structuresare offset by improved performance or if a premium price for a higher welfare product can be obtained is very limited. Many ideas for environmental enrichment need to be further developed and studied preferably in commercial trials with respect to broilers' use and the effect on their behavior and welfare before being implemented under commercial conditions .Some legal (e.g. in Switzerland and Austria) and welfare standards (e.g. "Initiative Tierwohl", a private German label) allow to count the area of elevated platforms regarding stocking density, thus the costs for elevated platforms may at least partly be compensated by enabling a higher stocking density [9].

The use of probiotics has the objective to improve gut health.Probiotics supplementation significantly improved growth performance and feed efficiency as well as reducing the population of intestinal *P. multocida*, enterobacteria, and mortality [10].Welfare improvements of pigs can be tackled through the provision of different types of enrichment material that favours the expression ofnatural behaviour. In order to comply with EU Directive 2008/120/EC most pig farmers use enrichment material that meets the minimum legal requirements, such as a chain, different types of wood or a hanging rope. Although straw is the best alternative enrichment material [11]. Their use is not compatible in intensive housing systems with slatted floors, because the provision of loose material may cause problems for the removal of manure. The question therefore is if there are alternatives that ensure higher level of pig welfare and also be economically feasible.

As the second strategy is concerned early detection of diseases allows rapid actions to prevent further spread and probably may increase treatment efficacy [12]. Continuous monitoring of changes in animal behaviour that occur during development of clinical signs of disease can have diagnostic value. Changes may occur in feeding, drinking and/or elimination behaviours, as well as posture and activity; they may be subtle and therefore require intensive observation by a stockperson [13]. However, human monitoring of behaviour is more challenging due to the increasing intensification of livestock keeping, and because of reduced contact between livestock and their keeper. Advances in automation, based for example on cameras (visual imaging), microphones, radio-frequency identification (RFID) and other sensors enable automatic (semi) continuous monitoring and reporting of behaviourin larger groups of animals [14,15].

Precision Farming techniques hold great promise for improving livestock management through automated monitoring, that is continuous and objective. Narrowing down the analysis in pig farms to the individual, with complementary sensors such as RFID, enables the reduction and rational use of antimicrobials, by only treating individuals in need of treatment.In the this paper the early detection of diseases in pigs has been investigated by analysing the use of radio-frequency identification (RFID) and video surveillance systems to identify abnormal drinking of feeding behaviour, whereas the same objectives have been tried to be reached for broilers by using elevated platforms connected automatic to weighing devices [16]. The third strategy, targeted use of medication solutions, reduces the need for antimicrobials by targeting individual pigs or sub-flocks of broilers for medication and by the use of non-conventional alternatives. For novel precision medication of pigs through the water system and dosing pumps, real-time signals of individual water consumption can be a tool for animal monitoring. Methaphylactic treatment is often considered as generating a relative over-use of antimicrobials, because the disease is not yet present in a proportion of treated animals. In a mixed group of symptomatic and non-symptomatic animals, medicine uptake and circulating levels show a huge variability [17] What is needed to reduce the amounts of antimicrobials used as well as treatment failures is a reduction of the number of treated animals and the optimization of the dosage regimes. A series of innovations belonging to the three above mentioned strategies has been tested in several research trials on experimental farms or in semi-commercial farms settings. The objective of this paper has been to assess the possible costs and benefits of the innovations for pig and broiler farmers, as this information may aid the decision of farmers to adopt the innovations on their farms. As the analysis is primarily based on experimental research data, the results should be treated with care as on farm implementation may produce different results. The study provides therefore a very first assessment of possible costs and benefits on the investigated innovations. The analysedinnovations concerning the improvement of resilience of animals have been on-farm hatching systems, elevated platforms and the use of probiotics on broiler farms and enrichment material in pig farms. Innovations related to the strategy of early detection were the use of RFID tags and cameras to monitor feed and water consumption of pigs and automatic weighing systems attached to elevated platforms in broiler farms. Finally the use of non-antibiotic feed and/or water additives which are currently commercially available within the European Union has been analysed in relation to their targeted use on individual farms in an attempt to reduce reliance on antibiotic metaphylactic treatments.

Materials and Methods

Study design

In order to estimate the costs and benefits of the eight above mentioned innovations an economic analysis has been carried out on technical research data collected in research trials. For each of the innovations technical research reports and publications have been analysed. The aim of this analysis was to collect key performance indicators of pig and broilers in order to establish the technical efficiency of the production processes.Starting point for the production costs of broilers in the countries was derived from Van Horne (2018). Based on this report a techno-economical simulation model has been developed in Excel, that allows for the estimation of the production costs of broilers in the countries, where the research [18] trials have been carried out.The Interpig database (2020) has been used as starting point for the production costs of pigs.For the experiments involving pigs the Interpig database has been directly used as simulation tool of the production costs of pigs. A data collection has been carried out in collaboration with the researchers, that have carried out their work on each of the eight innovations.

Partial budget methodology

To establish the technical and economic effect of the innovations the partial budgeting approach has been used in the current study. Partial budgeting is a planning and decision-making framework used to compare the costs and benefits of alternatives faced by a farm business. It focuses only on the changes in income and expenses that would result from implementing a specific alternative [19]. Partial budgeting is regularly used to compare alternative production practices in agriculture with limited data and has been used for the assessment of innovative practices in different livestock sectors [20,21] Specific data protocols have been designed in the current sudy with the overall objective to catch the impact of the innovations on the production costs of broilers and pigs. Data concern the technical performances (average daily growth, feed conversion rate, mortality etc), revenues and costs broken down by the main cost items such as feed costs, veterinarian and medicine costs and other variable costs. Particular attention has been dedicated to information concerning the costs and the use of antimicrobials. To assess the effect of the innovations, information has been collected concerning the change of the technical efficiency parameters and the investment and operational costs related to the innovations. With the partial budgeting methodology these data have been used to estimate the impact of the innovations on the overall production costs of pigs and broilers. The innovations may change fixed (capital and labour) and variable costs as well as revenues, due to changes in output prices. Technical performance parameters may change due to the introduction of the measures (e.g. feed conversion rate (FCR), piglets weaned per sow, mortality rates, average daily gain (ADG), etc.). A simulation of the change in investments, operational costs and revenues and of the technical performance parameters on the ex-ante baseline scenarios allows for an assessment of the costs and benefits of the proposed innovations.

Most of the innovations have been tested at experimental level and sometimes in semi-commercial conditions. Due to this circumstance the study has an explorative character. The study provides a first assessment of the possible economic impact of the innovations.

Results

Peri-hatching environment for chickens: on farm hatching (WUR)

The conventional hatchery hatched (HH), the hatchery-fed (HF) and on-farm hatching (OH) have been compared within the Healthy Livestock project in two experiments (one semi-commercial study and one experimental study) in order to analyse the effects of the different hatching systems on welfare and resilience characteristics of broilers coming from a young breeder flock in their early and late life [22,23]. It was expected that differences in animal welfare were the highest between conventional hatching in the hatchery (HH) and on-farm hatching (OH).

In the study of Giersberg et.al (2021), a wide range of animal welfare indicators have been assessed in a semi-commercial study with 3 consecutive batches containing broiler chickens of a young broiler breeder flock hatched in either HH, HF or OH. A discriminating effect of hatching system was found for Foodpad Dermatitis (FPD), where the conventional hatchery-hatched chickens (HH) scored worse on this key indicator with respect to the on-farm hatched chickens (OH). This result was already obtained also in two other studies, where chickens from on-farm hatching systems scored better for the welfare indicator FPD [24] but was not found in the experimental experiment where chickens of a young breeder flock were reared in small pens [25]. According to the semi-commercialstudy the OH and HF chickens coming from a young breeding flock had a better growth performance than conventional HH chickens (+3.2 to +4.4% body weight at day 39, respectively) and the body weight of the OH chickens at slaughter was higher followed by the HF and HH chickens respectively [26]. There was no difference in antimicrobial use between the hatching systems. For the semi-commercial study, a data protocol has been developed with the objective to cover eventual differences in productive performances between the chickens raised in the three systems. Next to these data, information was gathered about the investment costs of one alternative hatching system, namely the OH. Three batches of chickens have been followed for a total of about 13,800 broiler chickens in a semi-commercial setting. The early fed chickens in the two alternative systems had significantly higher initial weights at day 1 of age (+26.2%), higher weights at slaughter at day 39 (+4.4%), but comparable feed conversion ratios throughout the production cycle (Table) [27]. The chickens raised in the HC system showed performance results that were in between the HH and the OH system.From this, we can conclude that the early fed chickens raised in the alternative hatching systems showed a higher performance.

This was also confirmed in the second study of Molenaar et.al (2023) within the Healthy Livestock project. In this experimental study, a live attenuated IB vaccine virus was used to study disease resilience in chickens of young breeder flock offspring. No effect of hatching system on humoral immune response or disease resilience was found.

With the Excel simulation tool the baseline production costs have been calculated with a FCR of 1.58, an ADG of 47 gr/day, a 3.5% mortality rate and a final weight at slaughter of 2,350 gr per broiler starting from the costs calculated by Van Horne (2018). At these conditions, the costs per kg of liveweight are 80,0 €cts per kg. The following additional data have been collected [28-30] to take account of the changes due to OH system with respect to the HH system[1], as no further detailed information on the fixed costs is available for the

	Hatchery Hatched (HH)	Hatchery Fed (HF)	Onfarm Hatching (OH)
	4 pens of approx 1,141 chickens	4 pens of approx 1,141 chickens	4 pens of approx 1,141 chickens
No. of chickens in total	13,804	13,804	13,.804
Initial average weight (gr/chicken)	36.9	43.4	46.6
Average live weight at slaughter day 39 (gr/chicken)	2,635.0	2,719.4	2,751.4
Growing period (days)	39	39	39
Feed intake (kg/ animal/cycle)	3.82	3.96	4.05
Average daily growth	66.6	68.6	69.4
Feed conversion rate (kg feed/kg growth)	1.46	1.46	1.47
Mortality (%)	3.27%	4.39%	3.20%

Table 1: Technical performances of broilers in three alternative hatching systems.

HF system. With the HH system, the FCR was 1.46, ADG was 66.6 gr/day, mortality rate was 3.27% and final weight at slaughter was 2,635 gr per broiler, but with the OH system ADG reaches 69.4 gr/day (+4.2%), a mortality rate of 3.2%, but FCR did not change because of the higher feed intake. The investment costs in the OH system are on average € 1.37 per broiler place and the heating costs with on-farm hatching are approximately 10% higher, the purchase of incubated eggs is approximately 2.5 €ct lower that live one-day chicks. Finally labour increases by 4 hours per stable per day for the 3 additional days at the beginning of the production cycle. This additional work load is related to preparing the stable andadditional checks on the hatching chickens (Table 2).

Costs	Hatchery Hatched (HH)	Onfarm Hatching (OH)	% var.
Variable costs	13.62	10.73	-21.2
Purchase of chicks			
Feed	48.98	47.28	-3.5
Other variable costs	7.60	7.51	-1.2
Fixed costs	3.60	3.66	1.7
Labour			
Buildings	4.80	5.78	20.4
Overhead	0.80	0.77	-3.8
Disposal of manure	0.60	0.58	-3.3
Total costs	80.00	76.31	-4.6

Table 2: Total production costs of broilers in relation to two hatching systems (€cts/kg liveweight).

Effects of elevated platforms in poultry systems (FLI)

In a research trial carried out by FLI, three systems have been compared: elevated platforms with a perforated (plastic grid) platform, non-perforated littered platform (aluminium plate) and a control system without the presence of elevated platforms [31-34] Broilers were grown in the three systems in two stables and in two subsequent production cycles. Objective of this study was to analyse changes in the welfare conditions of the broilers between the three systems and in the productive performances. By means of a dedicated data protocol some production parameters have been collected in two trials. Based on animal-related indicators, no advantages of elevated structures compared to floor housing without elevated structures were shown during this experiment. However, the two trials had an effect on mortality, chest dirtiness, and foot pad lesions and hock burn changes. No bedding qualities were assessed during the fattening phase, but conclusions on the mentioned parameters [35,36] and its differences could be drawn by relative humidity. Due to the higher relative humidity at the end of the fattening phase in the control run, it could have led to a moister bedding and consequently to worse foot pads and heel cusps regardless of the presence of elevated platforms. In the table below the averages of some productive performances are shown. There was not information available about the feed conversion rate (FCR).

	Control	With grid as elevated platform	With aluminum plate as elevated platforms
No. of chickens	492	492	494
Initial average weight (gr/chicken)	45	45	45
Average live weight at slaughter (gr/chicken)	2959	3016	2928
Growing period (days)	40	40	40
Average daily growth (gr/day)	73	74	72
Mortality (%)	7,7	7,9	6,5

Table 3: Technical performances of chickens with and without elevated platforms.

No significant differences can be noted in the ADG between the three production systems. Only the mortality rate of the chickens were lower in the system with aluminum plates as platforms was 6.5% against 7.7% in the control group, but this difference cannot be attributed to the presence of elevated platforms. According to the private German animal welfare standard "Initiative Tierwohl" broiler farmers need to reduce their stocking rate by 10% in order to have the license to produce under this label.

Livestock producers must have evidence to show that they plan and maintain stocking densities in such a way that 35 kg live weight per m^2 of useable floor space is not exceeded on average over three successive rearing cycles. In compliance with German legal requirements broiler farmers maintain a stocking density of 39 kg live weight per m^2 [24]. A reduction to 35 kg per m^2 of course will raise the production costs of broilers significantly. The explanatory notes of animal welfare standard specifies that "for poultry also littered perforated levels can be used, if these and also the area underneath the level can be used animal friendly". The elevated levels can count with a maximum of 10% of the surface area. This would mean that the stocking density can turn back to 39 kg live weight when using littered perforated platforms. What does this mean for the overall production costs of broiler in Germany? Using as baseline the average production costs of broilers in Germany according to Van Horne (2018) a reduction of the stocking density of 10% will cause an increase of production costs by 1.9 %, as the fixed costs and other variable costs per kg live weight will increase, whereas the feed and purchase of chicks costs will decline proportionally to the number [37] of reared broilers in the barn. Investing in elevated platforms the density can turn back to 39 kg live weight per m^2, but of course the building costs and labour costs will increase. With respect to the baseline the cost increase can anyhow be limited to 0.5% per kg live weight. However, this increase in costs has to be compensated by the label scheme in order to eventually motivate farmers to participate (Table 4).

	Base DE	With reduced stocking density by 10%	Perforated littered platforms
	€ct/broiler		€ct/broiler
Total production costs	81,90	83,52	82,33
Purchase of chicks	13,83	13,83	13,83
Feed	49,77	49,77	49,77
Other variable costs	7,60	8,44	7,60
Labour	3,70	3,70	3,89
Buildings	5,80	6,44	6,04
Overhead	0,80	0,89	0,80
Disposal of manure	0,40	0,44	0,40

Table 4: Production costs of broilers with and without elevated platforms(€cts/kg liveweight).

Source: Elaborated by CRPA on Van Horne (2018).

Enrichment material in pig housing systems (QUB)

An experiment has been carried out to test the effect of root vegetables and jute bags as functional enrichment for pigs housed in slatted systems, which cannot accommodate straw provision. This material presents the advantage that it is edible, chewable, investigable, manipulable and consistent with EU guidelines [25]. The question posed in the present analysis is if this novel enrichment treatment is economically feasible. The benefits of using enrichment material in general have been investigated in many previous research trials and are related to the prevention of tail biting [26] and the reduction of stress [27]. Another highly important possible effect is the improvement of the feed conversion rate (FCR) of weaners and finisher pigs raised in enriched environments compared to pigs housed in barren pens. These effects have been tested in the above mentioned experiment both on weaners and finisher pigs. The basic question here then is, if the improvement of the technical performances of the pigs are able to compensate for the costs of the root vegetables and jute bags. In the research experiment different groups and categories of pigs have been compared. During the weaner stage the newly weaned pigs were allocated into two housing systems: standard (S) with plastic toy and wood and enriched (E) with the extra addition of jute bags and fooder beets.

During the finisher stage pigs were kept either in the [38-40] same enrichment treatment (SS and EE) or were switched from enriched to standard (ES) and vice versa (SE). A first analysis has been made of the costs of root vegetables and jute bags. During the weaner stage according to the market price of fodder beet of € 47,20/ton and a provision of 1.88 kg beet per pen per and per day the pig farmer will spend € 1.24 per pen or € 0.124 per weaner and € 0,094 per weaner for jute bags. During the finisher stage the farmer will bear a cost of € 7.98 per pen, which means € 0.57 per finisher pig. For jute bags the expenditure will be € 0.13 per finisher pig. From this it turns out that the costs of enrichment material is very limited. From the experiment a significant improvement of FCR has been obtained when using this enrichment material. The table below reports the average outcomes of the study for the weaner stage (Table 5).

	Standard	Enriched	% var.
Average Daily Feed Intake	0.85	0.82	
Body Weight	33.7	33.4	
Feed conversion rate	1.50	1.44	4.0

Table 5: Technical performances of pigs in standard and enriched environment.

As the finisher stage is concerned, also in this case the Feed Conversion Rate for the finisher pigs is better for those finished with fodder beet and jute bags. The next table shows the main average results of this research trial (Table 6).

	Standard	Enriched	Switch from Enriched to Standard	Switch from Standard to Enriched
Average Daily Feed Intake	2.71	2.62	2.75	2.60
Body Weight	117.0	119.2	120.8	116.2
Feed conversion rate	2.41	2.31	2.28	2.40

Table 6: Technical performances of pig in standard and enriched environment.

Source: Buckova et.al. 2022

Of interest is to know what at the balance are the costs and benefits for both the weaner and finisher stage. To this end data with the Interpig database the impact of the change in the technical performances and the costs of the enrichment material on the cost of production of weaners [41,42] and finisher pigs have been calculated. The average data of the production costs of the United Kingdom have been used as the baseline scenario (Table 7 & 8).

	UK 2020	With enrichment
Rearing Feed	1,71	1.64
Feed, (euro/piglet)	35,14	33,73
Other variable costs, (euro/piglet)	12,99	13,21
Labour, (euro/piglet)	6,81	6,81
Finance cost, (euro/piglet)	10,68	10,68
Total costs, (euro/piglet)	65,62	64,43

Table7: Production costs of rearing pigs with and without enrichment material.

The improvement of the technical performances due to the use of enrichment material causes a reduction of the production costs of weaners by 1.8%.

The improvement of the technical performances due to the use of enrichment material causes a reduction of the production costs of finishing pigs by 2.2 %.The better FCR due to the use of fodder beets and jute bags more than compensates for the costs of this enrichment material.

	UK 2020	With enrichment
Rearing Feed Conversion Ratio	2.67	2.52
Piglet cost, (euro/slaughter pig)	68.55	67.32
Feed, (euro/slaughter pig)	57.98	54.80
Other variable costs, (euro/slaughter pig)	7.14	8.34
Labour, (euro/slaughter pig)	4.75	4.75
Finance cost, (euro/slaughter pig)	5.53	5.53
Total costs (euro/slaughter pig)	143.96	140.74

Table 8: Production costs of finishing pigs with and without enrichment material.

Supporting chicken gut health through probiotics (NRVI)

Probiotics have the potential to generate immune stimulatory effects and improve gut health of chicken. A research trial has been carried out by NRVI where 2 farms [43-45] have used only probiotics, 2 farms using a cocktail of probiotics and antibiotics, 2 farms that used only antibiotics and finally a control group of 2 farms that did not use neither antibiotics nor probiotics (Niczyporuk under review). Although the farms are different, the same hatchery has been used for the purchase of the chicks and all farms have used the same feed company to buy their feed. The objective of this study was to investigate how the health status of chickens can be improved by using probiotics. Based on the data collected with a dedicated protocol the following results have been obtained (Table 9).

	Only probiotics	No antibiotic and no probiotics	Probiotics and antibiotics	Only antibiotics
No. of chickens	60	60	60	60
Initial average weight (gr/chicken)	41.25	39.75	40.75	42.00
Average live weight at slaughter (gr/chicken)	2,500	2,100	2,397	2,350
Growing period (days)	42	42	42	42
Average daily growth (gr/day)	58.5	49.1	56.1	55.0
Feed conversion rate (kg feed/kg growth)	1.66	1.61	1.63	1.61
Mortality %	**1.3**	**2.7**	**4.0**	**5.4**

Table 9: Technical performance of chickens raised with different use of probiotics and antibiotics.

Two comparisons can be made. In the first group which uses probiotics is compared with the group that uses any drug at all. From this comparison it turns out that in [46] the control group the mortality is the higher (2.7%) than in the group that uses probiotics (1.3%). Moreover, the chickens with probiotics have a significantly higher daily growth, with a slightly worse feed conversion rate (1.66 against 1.61). With the use of only probiotics the broilers reach a higher live weight at slaughter, but this implies the use of more feed per kg of meat. According to the trial data the mortality of the group of chickens finished with the use of only probiotics in the diet is only 1.3%, which partially compensates for the worse FCR. When group 3 and 4 are compared again the chickens with probiotics have a mortality with respect to the group that uses only antibiotics. Also differences in ADG and FCR are encountered between these two groups, but these are not significant [47-49]. The differences in mortality rate, feed efficiency and average daily growth have been simulated on the baseline production costs of broilers in Poland (Van Horne, 2018) leaving all other cost items unchanged. With this partial budget analysis it turns out that the production costs of the groups of chickens raised with only probiotics are the lowest, which is in particular due to the low mortality rate. With respect to the two control groups (2 and 4) the production costs are respectively 2.5% and 0,9% lower in the groups that use probiotics (Table 10).

	€ct/kg live weight	€ct/kg live weight	€ct/kg live weight	€ct/kg live weight
Total costs	77.44	79.40	79.23	80.03
Purchase of chicks	12.82	15.48	13.74	14.22
Feed	51.38	50.55	51.88	52.00
Other variable costs	6.60	6.70	6.79	6.89
Labour	1.48	1.50	1.52	1.54
Buildings	4.63	4.70	4.76	4.83
Overhead	0.59	0.60	0.61	0.62
Discharge manure	-0.10	-0.10	-0.10	-0.10
Probiotics and/or antibiotics	0.031		0.036	0.031

Table 10: Production costs of chickens raised with different use of probiotic and antibiotics in Poland (€cts/kg liveweight).

Early detection of health and welfare challenges based on behaviour of groups of pigs in commercial settings (QUB and IFIP)

The present strategy to reduce the use of antimicrobials belongs to the category of early detection of diseases. Several techniques applying the principles of precision livestock farming can be implemented to detect in an early phase the emergence of health problems, such as digestive ore respiratory diseases. Automatic monitoring of pigs with a variety of sensors is a way to identify unusual behaviour, that may be considered an early warning to the pig farmer to investigate the health status of individual or groups of pigs [50-52]. In the present trial the objective was to early detect diarrhoea in weaned pigs using automata recording of individual weights and feed and water intake of pigs equipped with RFID tags. Groups of light, medium and heavy weaned piglets were observed, their water and water consumption was registered and their weights were measured. During the trials a high intra-individual variability of watering and feeding was noted, which has complicated the discrimination of diarrheal animals from healthy animals. In particular the amounts of water drunk do not seem to be relevant for early detection of the onset of diarrhoea [28]. More promising seemed to be the variation in feed consumption. Animals with diarrhea consumed significantly less feed relative to their weight than healthy animals during the first week after weaning, for data 24 and 48 h before first clinical signs. However, despite this difference, machine learning methods failed in detecting individually diarrheicanimals from feed consumption related to weight, because of considerableindividual variability. This all makes automatic detection of diseases with RFID difficult, in particular for a commercial use of this technology because other parameters than health may influence feed intake (the composition of the feed, the breed, the environment etc). Based on these outcomes of the research trial no analysis of costs and benefits have been carried out of systems based on RFID Automated recording of feeding behaviour still can potentially be a useful tool for the early detection of health and welfare challenges of commercial pigs (Matthews et al, 2016. Several methods can be used to record feeding behaviour such as RFIDwith electronic ear tags, but also with video surveillance. In the following analysis a 2D camera-based deep learning method has been tested with the objective to be used on a commercial basis . With this tool several types of behaviour can be monitored and not just feeding or drinking behaviour, but here we concentrate on the former.The method measured visits to the feeding station, as an indicator of feeding behaviour. It showed to be robust enough to apply under a variety of circumstances, e.g. fluctuations in natural lighting and pig body size. Moreover, the method was? capable of distinguishing between feeding and non-nutritive visits (NNV) to the feeding area. With respect to other video surveillance systems the present method was faster and did not require substntial modifciation by the capture software.

The value of changes in NNV behaviour has shown to be a sensitive indicator of declining health and welfare problems of pigs [29]. The automated video recording of feed and/or NNV behaviour is able to identify subtle changes that are impractical to quantify manually and therefore early detection, through automation, allows for timely intervention to prevent a further reduction in animal welfare and associated economic losses.

The costs and benefits analysis of this method takes into account the following possible changes:

1. The investment costs in the 2D cameras
2. Costs associated with the licencing of the developed software
3. Costs associated with the maintenance of the system, such as checking for camera operation or lens cleaning
4. The reduction of eventual economic losses due to the occurrence of health and welfare challenges

The baseline for the analysis of costs and benefits was the UK production costs of 2020 as presented by the Interpig database. The farmer may be interested to invest in this system, as it can provide the farmer with alarms concerning individual pigs or groups of pigs that show 'abnormal' behaviour as their health or welfare status is being compromised. The assumption is that the camera equipment will not be set in every pen within a pig house and that a number of 'sentinel' pens will be used as indicators of the health and welfare status of the operation. In the case of large pens with a large number of pigs it has been estimated that or a pig operation with 2,000 pigs for example 5-6 cameras will be needed to cover the whole pen. The costs of the licence hire of the data capturing system, including data storage and processing, is around £3,500 (3500*1,14=€ 3.990), but this will be expected to reduce as the technologies develop. The principle of the system is that the alerts will be automatic so the farmer is informed and no extra labour costs will be needed. At an investment of € 821 the annual capital costs of the system will be around € 118. Together with the yearly costs of the data capture system this implies a yearly costs of € 4,108. For a 2,000 pigs farm this early warning system would increase the production costs by 1,5%. In terms of the reduction in diseases due to the implementation of the developed technology, this is something that has yet to be estimated, but it can be stated that a cost increase of 1.5 % might be an interesting investment to prevent in time an outbreak of an important disease that may compromise the survival of the farm or may generate huge costs to recover. The economic feasibility of these yearly costs depends on the gross margin the pig farmers is able to realize. However, significant costs can be saved if the farmer acts in time (Matthew Rendleman et.al, 1999) According to a meta-analysisof over 130 studies carried out over the period 1995 – 2015 and a consultation of 55 key stakeholders production diseases can raise the costs of production up to 30 – 40 € per pig (Niemi et.al, 2018).The economic impact of pig diseases can be significant in terms of an increase of veterinary, medicine costs and labour costs, but also on the physical performance of pigs.

Respiratory diseases may generate a reduction of the gross margin per pig by 40%, due to a greater variation in carcass weights, which leads to a reduction in revenue per pig (Pfuderer et.al, 2022).Porcine Reproductive and Respiratory Syndrome (PRRS) has been estimated to add between $5.60 and $7.62 to the cost of every pig sold in the US (Johnson et.al, 2005). Another study reports that the losses per sow due to PRRS may range from € 127 up to € 650 (Nathues et.al, 2017).

Rapid detection of health problems with automatic weighing systems in broilers (FLI)

FLI has used the output from electronic weighing beams attached under the elevated platforms developed in 3.2 to continuously monitor the activity of broiler chickens. The focus is on weight changes in the platform as a result of birds entering and leaving the platform. Measures of weight changes and also of the total number of birds on platforms (estimated by their weight) has been used to automatically record changes in activity and in the use of the elevated platform. Based on these automatic data algorithms can be developed to detect significant temporal changes, signalling possible health problems to the farmer online. The development and testing of both the technical features and the software has been done using 3 groups of 200 broilers each throughout two trials (Schomburg et al., 2023). In the final phase of this work, the program for rapid detection has been tested in commercial flocks of broilers on a farms by combining traditional methods for health assessment with the automated rapid detection program.. This phase was focused on the ability of the rapid detection system to detect specific health problems in a commercial production environment. These methods have been combined with the weighing platform. The interrelation between the different automated methods will be analysed with respect to the specificity and sensitivity for health problems. This analysis will be used to further adapt and optimize the algorithms for the online detection of health problems by the activity monitoring platforms. As the costs and benefits of this system are concerned the following information has been used. In a barn with approx. 30,000 broiler chickens just one row of platforms is needed. In the study on the commercial farm, a 68 m of elevated platform has been used with additional three elevated platforms with weighing systems at a cost of:.

- 3 weighing system (length * width: 2m * 0,6m): 3* 418€ = 1,254€
- elevated platforms: approx. 9,104 €
- 3 hours extra labour time has been taken into account to clean and disinfect the platforms and the weighing systems

The yearly costs of these systems would be € 1,352. for the elevated platforms and € 186 for the elevated platforms with weighing system. In the par.3.2. the costs and benefits of the elevated platforms have been analysed with a cost increase of 0.5% per kg live weight taking into account that the platforms can be used as useable area for the broiler. The addition of the weighing devices generates just a further increase of the production costs, but to very limited extent, as is shown in the table below (Table 11).

	Base DE	With reduced stocking density by 10%	Perforated littered platforms	Platforms with weighing systems
	€ct/broiler		€ct/broiler	€ct/broiler
Total costs	81,90	83,52	82,33	82,42
Purchaseof chicks	13,83	13,83	13,83	13,83
Feed	49,77	49,77	49,77	49,77
Other variable costs	7,60	8,44	7,60	7,60
Labour	3,70	3,70	3,89	3,95
Buildings	5,80	6,44	6,04	6,07
Overhead	0,80	0,89	0,80	0,80
Disposal of manure	0,40	0,44	0,40	0,40

Table 11: Production costs of broilers with and without elevated platforms endowed with weighing systems(€cts/kg liveweight)

Source: Elaborated by CRPA on Van Horne (2018)

The weighing system has been developed with the intention of providing a tool for the (early) detection of animal welfare related issues, such as health or behavioural problems. To achieve this, further test runs are necessary, but first results indicate that the weighing system can give information about both changes in weight gain and behavioural anomalies e.g. resulting from health problems during the fattening period. Diseases of the intestinal tract of poultry, caused by bacteria or parasites, are responsible for animal welfare problems as well as great economic losses. Body weight gain is negatively influenced for infected birds (Sand, 2016). In addition, activity of infected birds often is reduced (Bessei, 2006).

Thus, the objective is to detect an early outbreak by monitoring daily body weight and changes in the usage of the platform. Automatic real-time monitoring of the estimated daily mean weight, the usage of and the activity on the platform are promising measures that could be used for early detection of infections.

Targeted application of tailor-made feed and water additives (VTN INRA)

The purpose of this pilot field study was to use historical fact-based information specific to each farm covering biological performance data, health data and veterinary diagnoses and consequent interventions to arrive at the most appropriate selection of non-antibiotic additive(s) targeted so as to best counter specific problems identified to the farm. The parameters monitored were in addition to biological performance indices, the use of antibiotic treatments in terms of both number and duration.Commercial broiler farms in two EU countries (Greece and Cyprus) were involved in this study. All farms were selected on the basis that they had a consistent and relatively high reliance on antibiotic usage in their most recent historical growing cycles (extending up to the twelve months previously). As such they were not selected to be representative of each country in either biological performance or antimicrobial usage. At the onset of the study two complete and consecutive production cycles, post any biosecurity improvements but before any targeted additive interventions took place, were monitored through visits and data collection by the research team involved while always with the consent and help of the farmer and his veterinary consultant. As such they were not selected to be representative of each country in either biological performance or antimicrobial usage. Historic antimibiotic usage records were also made available as was the veterinary diagnosis where applicable as attached to each production cycle. Moreover, information on the water quality, where the source was farm wells, was also procured. These information bases provided the platform upon which discussions involving the farmer, his veterinary consultant and researchers participating in this study took place so as to arrive at an agreed individual farm focused intervention. All such individual farm-based interventions made use of commercially available and approved feed and/or water additive regimes best targeted at a possible reduction of antibiotic use at each specific site while also maintaining similar biological performance as measured by the parameters described above.Such additives ranged from prebiotics, probiotics, essential oils, phytogenics as well as organic acids and their combinations. All participating broiler farms were arranged into five groups AG, BG, AC, BC and CC. For each sub group specific tailor made feed and/or water additive regimes based on commercially available products were prepared (Table 12).

	Mortality Rate	FCR	Number of AB Treatments	Days of AB Treatments	AB costs	Additive cost
Pre- Additive Period	4.22	1.65	1.91	4.39	380,31	0
Post Additive Period	2.65	1.60	0.95	3.45	212,53*)	369,93
% change	37.2	3.0	12.1	21.4	44.1	n.a

Table 12: Average biological performance, antibiotic (AB) use and costs of AB and additives during the two pre and two post additive production cycles.

Table 12 reports the results of this innovative in field practice. The use of additives creates a series of positive effects. The mortality rate of the broilers goes down by 37% and the feed conversion rate by 3%. Most important is also the reduction of the use of antibiotics: the number of treatments declines by 12% and the days of treatment by 21%. Together this causes a reduction of the use of antibiotics at constant prices of 44%. Of course the costs of the additives have to be taken into account, as these reach on average about € 370 per cycle. These data of changes in the technical performance and in the costs of antibiotics and additives have been used to calculate the overall economic impact of this practice. As baseline the average production costs of broiler farms in Greece and Cyprus have been used with a mortality rate of 4.22% and feed conversion rate of 1.65 kg of feed per kg of growth. The reduction of the mortality rate from 4.22% to 2.65% and the improvement of the feed conversion rate to 1.60 generates a reduction of the production costs by 3.4% (86,39 to 83,42 €cts/kg). After consideration of the reduction of the costs of antibiotics and the increased costs due to the use of additives the final production costs of the broilers arrives at €cts 83,92/kg of live weight. At the balance the use of additives finally reduces the production costs by 2.86%.

On broiler farms where there is a high historic reliance on the use of antibiotics from the economic, as well as the societal point of view, his practice can be considered highly convenient and effective. This is because it can improve the productive performance of the broiler farms and in parallel reduces the use of antibiotics which creates ample opportunity for the compensation of the costs of the additives.

	Pre intervention		Post intervention	
	€ct/kg live weight	€ct/head/cycle	€ct/head/cycle	€ct/kg live weight
Total costs	86,39	205,70	199,81	83,92
Purchase of day old chicks	13,44	32,00	31,48	13,22
Feed	53,54	127,48	121,63	51,08
Other variable costs	11,65	27,74	27,29	11,46
Antibiotics	0,96	2,29	1,28	0,54
Labour	1,50	3,57	3,51	1,48
Buildings	4,70	11,19	11,01	4,62
Additives	0,00	0,00	2,20	0,92
Overhead	0,60	1,43	1,41	0,59

Table 13: Production costs of broilers before and after the targeted use of additives alternative to antibiotics(€cts/kg liveweight).

Discussion

The current paper has provided insight in the possible costs and benefits of innovative practices, that are potentially able to reduce the use of antimicrobials. The innovations belonged to three different strategies: "increase of resilience", "early detection" and "targeted use of antimicrobials". Previous research has shown that more resilient and robust animals are able to better face the challenges of diseases, which may lead to a reduced use of antimicrobials. In the Healthy Livestock project, the highest emphasis has been placed on the improvement of resilience. On farm hatching and the use of probiotics are tools that farmers can implement on their farms to improve the welfare and possibly resilience of broilers.

This first economic analysis on a very limited dataset has shown, that the improvement of the technical performances of the broilers induced by the use of these practices may compensate for the investment costs. Effectively in practice broiler farmers already show interest to invest in on farm hatching and probiotics. Less attractive from the economic point of view seems to be the use of elevated platforms, but if these platforms can be used as useable area for broilers the production costs of broilers are come close to the costs of a conventional system. The analysis dedicated to the use of enrichment material for finishing and rearing pigs clearly shows that the use of jute bags and root vegetables can be efficient and economically convenient material. It was however not been possible to show the impact of the practices on the reduction of the use of antimicrobials, because often the research has been carried out in experimental settings. This holds for almost all innovative practices analyses in this research: the innovations have the potential to reduce the use of antimicrobials but this takes more time than the timeframe of the research experiments. An exception to these findings is the targeted use of feed and/or water additives, which, if appropriately targeted to the specific farm's situations, allows for a significant reduction of the use of antibiotics, particularly where such use is high. The NVRI studies showed the beneficial properties of probiotic supplementation, which were used in various combinations and various supplementation schemes on broiler chicken farms in Poland. These products (probiotic/prebiotic) play a significant role in maintaining the proper immunological status of the tested flocks and increasing the level of immune antibodies, improving the intestinal flora and thus maintaining the proper balance in the microbiome of properly managed poultry flocks. Experimental studies confirm this relationship. The obtained results suggest that supplementation with products containing probiotics/prebiotics may have a positive effect on the immunity of poultry flocks, which enhance their resilience against diseases and indirectly favors the economic convenience of this practice.

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References

1. Colditz IG, Hine BC (2016) Resilience in farm animals: biology, management, breeding and implications for animal welfare. Animal Production Science 56: 1961-1983.

2. Doeschl-Wilson A, Knap PW, Opriessnig T, More SJ (2021) Review: Livestock disease resilience: from individual to herd level. Animal the International Journal of Animal Sciences 15: 100286.

3. D'Eath RB, Arnott G, Turner SP, Jensen T, Lahrmann HP, et al. (2014) Injurious tail biting in pigs: how can it be controlled in existing systems without tail docking? Animal 8:1479 -1497.

4. de Jong IC,Blaauw XE, van der Eijk JAJ, Souza da Silva C, van Krimpen MM, et al. (2021) Providing environmental enrichments affects activity and performance, but not leg health in fast- and slower-growing broiler chickens.Appied Animal Behaviour Science 241: 105375.

5. https://www.tierschutzlabel.info/fileadmin/users/redakteur/redakteur_upload/Masthuehner/2023/RevInfo_RL_Masthuehner_2023.

6. Fasina FO, Lazarus DD, Spencer BT, Makinde AA, Bastos AD (2012) Cost implications of African swine fever in smallholder farrow-to-finishunits: economic benefits of disease prevention through biosecurity. TransboundEmerg Dis 59:244-255.

7. Fraser RW, Williams NT, Powell LF, Cook AJC (2010) Reducing campylobacter and salmonella infection: two studies of the economic cost and attitude to adoption of on-farm biosecurity measures. Zoonoses Public Health 57: 109-115.

8. Gunn GJ (2008) Measuring and comparing constraints to improved biosecurity amongst GB farmers, veterinarians and the auxiliary industries, Preventive Veterinary Medicine 15: 3-4.

9. https://initiative-tierwohl.de/wp-content/uploads/2021/06/2021-07-21_Handbuch-Kriterienkatalog-ITW-Gefluegel-1.pdf

10. Reuben R, Reuben S, Sarkar H, Ibnat MA, Roy I, et al. (2022) Multi-strain Probiotics Upregulated Anti-inflammatory Properties and Reduced Pasteurellamultocida Mortality in Broilers. International Journal of Infectious Diseases 116: 56.

11. Riber AB, van de Weerd HA, de Jong IC, Steenfeldt S (2018) Review of environmental enrichment for broiler chickens. Poultry Science 97: 378-396.

12. Matthews, Stephen G, Miller AL, Clapp J, Plötz T, et al. (2016) Early detection of health and welfare compromises through automated detection of behavioural changes in pigs. The Veterinary Journal 217:43-51.

13. Van Hirtum A, Berckmans D (2003) Fuzzy approach for improved recognition of citric acid induced piglet coughing from continuous registration. J Sound Vib 266: 677-686.

14. Aydin A, Cangar O, Ozcan SE, Bahr C, Berckmans D (2010) Application of a fully automatic analysis tool to assess the activity of broiler chickens with different gait scores. Computers and Electronics in Agriculture 73: 194-199.

15. Kyriazakis I, Alameer A, Buˇcková K and Muns R (2023) Toward the automated detection of behavioral changes associated with the post-weaning transition in pigs. Front Vet Sci 9: 1087570.

16. Schomburg H, Malchow J, Sanders O, Knöll J, Schrader L (2023) Elevated platforms with integrated weighing beams allow automatic monitoring of usage and activity in broiler chickens. Smart Agricultural Technology 3: 100095.

17. Weber NR, Pedersen KS, Hansen CH, Denwood M, Hjulsager CK, et al. (2017) Batch medication of intestinal infections in nursery pigs—A randomised clinical trial on the efficacy of treatment strategy, type of antibiotic and bacterial load on average daily weight gain, Preventive Veterinary Medicine. 137: 69-76.

18. Van Horne P (2018) Competitiveness of the EU poultry meat sector, base year 2017: international comparison of production costs. Wageningen Economic Research.

19. Roth S, Hyde J (2002) Partial budgeting for agricultural businesses, Report of Pennsylvania State University

20. Léger A, Lechner I, Pont J, Kaske M, Feldman M, et al. (2021) Income compensation options and partial budget analysis following a reduction of antimicrobial sales at the veterinary practice level. Preventive Veterinary Medicine 192: 105372.

21. Rowe SR, Nydam DV, Godden SM, Lago A, Vasquez AK, et al.(2021) Partial budget analysis of culture- and algorithm-guided selective dry cow therapy. Journal of Dairy Science 104: 5: 5652-5664.

22. Giersberg MF, Molenaar R, de Jong IC, Souza da Silva C, van den Brand H, et al. (2021) Effects of hatching system on the welfare of broiler chickens inearly and later life, Poultry Science100946.

23. Molenaar R, Stockhoe-Zurwieden N, Giersberg MJ, Bas Rodenburg T, Kemp B, et al. (2023) Effects of hatching system on chick quality, welfare and health of young breederflock offspring. Poultry Science 102: 102448.

24. TierSchNutzt V (2021) Verordnung zum Schutz landwirtschaftlicher Nutztiere und anderer zur Erzeugung tierischer Produkte gehaltener Tiere bei ihrer Haltung (Tierschutz-Nutztierhaltungsverordnung – TierSchNutztV)

25. European Commission (2016) Commission Staff Working Documenton best practices with a view to the prevention of routine tail-docking and the provision of enrichment materials to pigs Brussels, 8.3.2016 SWD(2016) 49 final

26. Lahrmann HP, Hansen CF, D´Eath RB, Busch ME, Nielsen JP, et al. (2018) Early intervention with enrichment can prevent tail biting outbreaks in weaner pigs. Livestock Science 214: 272-277.

27. Casal N, Manteca X, Escribano D, Ceròn JJ, Fabrega E (2017) Effect of environmentalenrichment and herbal compound supplementation on physiological stress indicators (chromogranin A, cortisol and tumour necrosis factorα) in growing pigs. Animal 11.

28. Thomas J, Rousselière Y, Marcon M, Hémonic A (2021) Early Detection of Diarrhea inWeaned Piglets From IndividualFeed, Water and Weighing Data, Frontiers in Animal Science 2: 688902.

29. Bučková K, Muns R, Cerón J, Kyriazakis I (2022) Consequences of timing of organic enrichment provision on pig performance, health and stress resilience after weaning and regrouping. Animal 16.

30. Bergevoet R (2019) Review: Livestock disease resilience: from individual to herd level. Den Haag 16.

31. Bessei W (2006) Welfare of broilers: A review. World Poultry Sci J 62: 455-466.

32. Bučková K, Muns R, Cerón J, Kyriazakis I (2022) Consequences of timing of organic enrichment provision on pig performance, health and stress resilience after weaning and regrouping. Animal 16.

33. Heikkilä J (2011) Economics of biosecurity across levels of decision-making: a review. Agronomyfor Sustainable Development Springer Verlag/ EDP Sciences/INRA31: pp.119-138.

34. Johnson C, Mabry J, Kliebenstein J, Neumann E (2005) The impact of PRRS on the pig production costs; Iowa State University Animal Industry Report

35. Mallioris P, Dohmen W, Luiken REC, Wagenaar JA, Stegeman A, et al. (2022) Factors associated with antimicrobial use in pig and veal calf farms in the Netherlands: a multi-method longitudinal data analysis. Preventive Veterinary Medicine 199: 105563.

36. Matthews M, Stephen G, Miller AL, Clapp J, Plötz T, et al. (2016) Early detection of health and welfare compromises through automated detection of behavioural changes in pigs. The Veterinary Journal 217:43-51.

37. Matthew RC. Spinelli FJ (1999) The costs and benefits of animal disease prevention: the case of african swine fever in the US. Environmental Impact Assessment Review. 19: 405-426

38. Niemi JK, Sahlstrom L, Kyyro J, yytikainen L, Sinisalo A (2016) Farm characteristics and perceptions regarding costs contribute to the adoption of biosecurity measures in Finnisg pig and cattle farms. Review Agriculture Food Environment Studies 97: 215-223.

39. Nathues HP, Alarcon J, Rushton R, Jolie K, Fiebig M,et al. (2017) Cost of porcine reproductive and respiratory syndrome virus atindividual farm level – An economic disease model. Preventive Veterinary Medicine 142: 16-29.

40. Pfuderer S, Bennett RM, Brown A, Collins LM (2022) A flexible tool for the assessment of the economic cost of pig disease in growers and finishers at farm level. Preventive Veterinary Medicine 208: 105757.

41. Postma M, Backhans A, Collineau L, Loesken S, Sjoland M, et al. (2016) The biosecurity status and its associations with production and management characteristics in farrow-to-finish pig herds. Animal 10: 478-489.

42. Reuben R, Reuben S, Sarkar H, Ibnat MA, Roy I, et al. (2022) Multi-strain Probiotics Upregulated Anti-inflammatory Properties and Reduced Pasteurellamultocida Mortality in Broilers. International Journal of Infectious Diseases 116: 56.

43. Riber AB, van de Weerd HA, de Jong IC, Steenfeldt S (2018) Review of environmental enrichment for broiler chickens. Poultry Science 97: 378-396.

44. Rojo-Gimeno C, Dewulf J, Hogeveen H, Lauwers L, Wauters E (2016) Farm-economic analysis of reducing antimicrobial use whilst adopting improved management strategies on farrow-to-finish pig farms. Preventive Veterinary Medicine 129: 74-87.

45. Roskam JL, Oude Lansink AGJM, Saatkamp HW (2019) The technical and economic impact of veterinary interventions aimed atreducing antimicrobial use on broiler farms. Poultry Science 98: 6644-6658.

46. Roth S, Hyde J (2002) Partial budgeting for agricultural businesses, Report of Pennsylvania State University.

47. Sand JM, Arendt MK, Repasy A, Deniz G, Cook ME (2016) Oral antibody tointerleukin-10 reduces growth rate depression due to Eimeria spp. infection inbroiler chickens, Poultry Science 95: 439-446

48. Simon K, de VriesReilingh G, Bolhuis JE (2015) Early feeding and early housing conditions influence the response towards a noninfectious lung challenge in broilers, Poultry Science 94: 2041-2048.

49. Souza da Silva C, Molenaar R, Giersberg MF, Bas Rodenburg T, de Jong IC (2021) Day-old chicken quality and performance of broiler chickens from 3 different hatching systems, Poultry Science 100: 100953.

50. Uehleke R, Seifert S, Huttel S (2021) Do Animal Welfare Schemes Promote Better Animal Health? An Empirical Investigation of German Pork Production, Livestock Science 247:104481.

51. Van de Weerd HA , Day JEL (2009) A review of environmental enrichment for pigs housed in intensive housing systems. Applied Animal Behaviour Science 116: 1-20.

52. De Roest K, Montanari C, Ferrari P, Fourichon C, Levallois P, et al. (2023) Costs and Benefits of the Improvement of Biosecurity on Pig and Broiler Farms. Journal of Animal Research and Veterinary Science 7: 041.