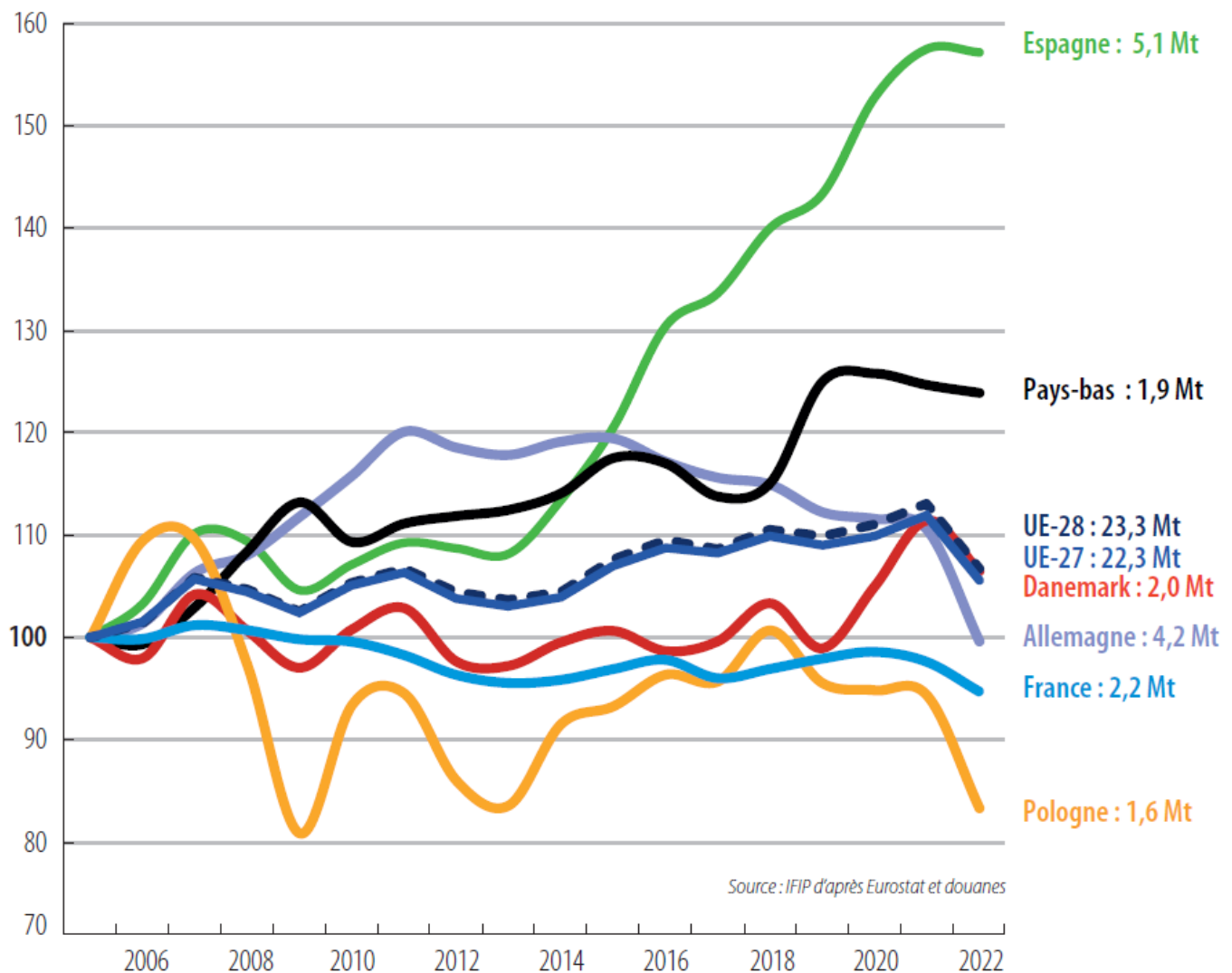


The Global and European Pork Industry: An Overview from IFIP



Institut du Porc (IFIP), the French pork research and development institute and a key player in the French agricultural sector, has recently published its 2024 report, titled [Porc par les Chiffres 2023-2024](#). The document provides a comprehensive overview of the global, European, and French pork industries and is a critical resource for all industry professionals.

The Global Pork Industry

The global pork industry has experienced significant changes over recent years. In 2021, global pork production reached approximately 108 million tons of carcass weight equivalent (CWE), largely driven by China's recovery from African Swine Fever (ASF). By 2022, global production continued to rise, though at a slower pace due to the stabilization of China's pig herd. However, the global landscape remains varied with notable regional differences.

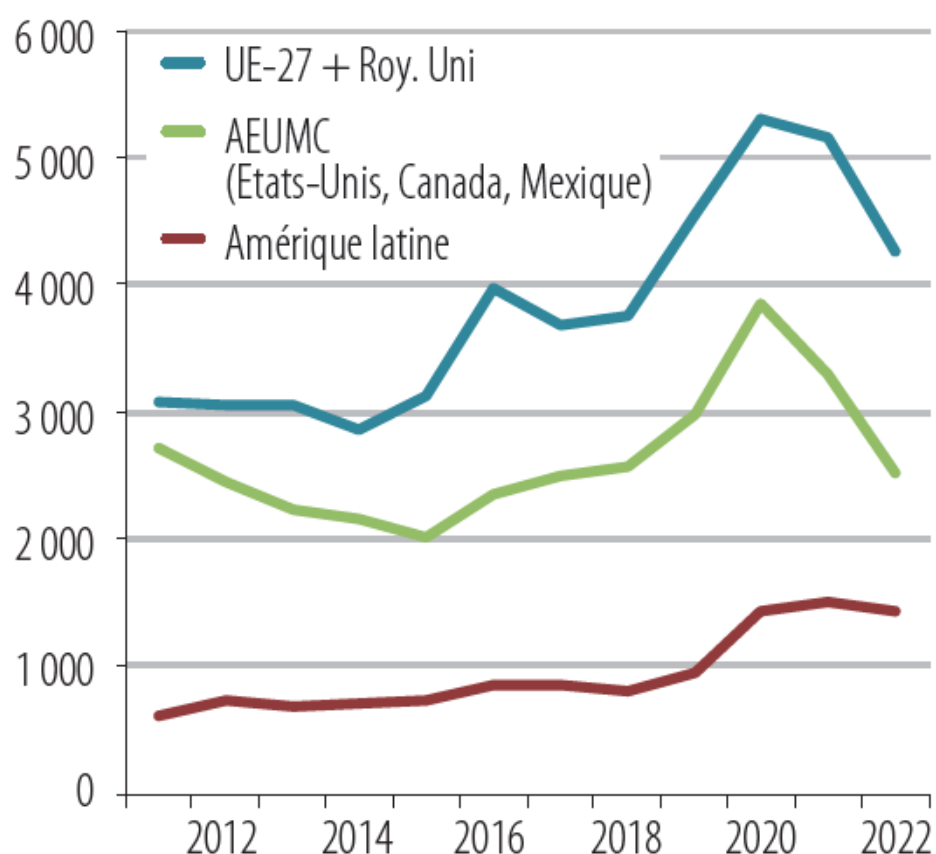


Figure 1. Main pork exporters (in 1000 tons)*

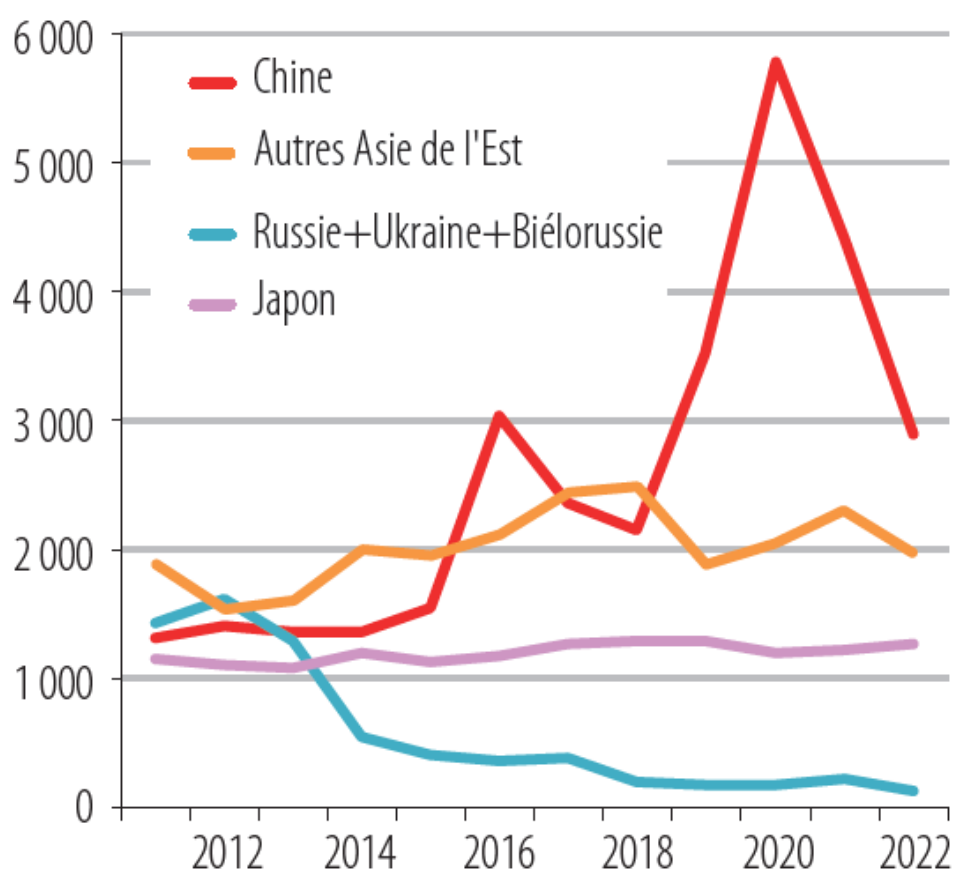


Figure 2. Main pork importers (in 1000 tons)*

*Excluding intra-EU and intra-EUMCA-EU trade evolving: EU15 (2000-2003), EU25 (2004-2006), EU27

(2007-2013), EU28 (2014)

In Asia, China dominates pork production, contributing 47.5 million tons in 2021. Other significant producers include Vietnam, Japan, South Korea, and the Philippines. In Europe, the EU-28 collectively produced 24.6 million tons, with Germany, Spain, and France being the leading producers. In the Americas, the United States and Brazil are major contributors, with the U.S. producing 12.6 million tons and Brazil 4.4 million tons. The production in other regions like Africa and Oceania remains relatively small in comparison.

The global pork trade is equally dynamic. In 2022, the major exporters included the European Union, the United States, and Canada. Key importers were China, Japan, and Mexico. The shifting demands and production capacities have led to fluctuating trade patterns, impacting global pork prices and market stability.

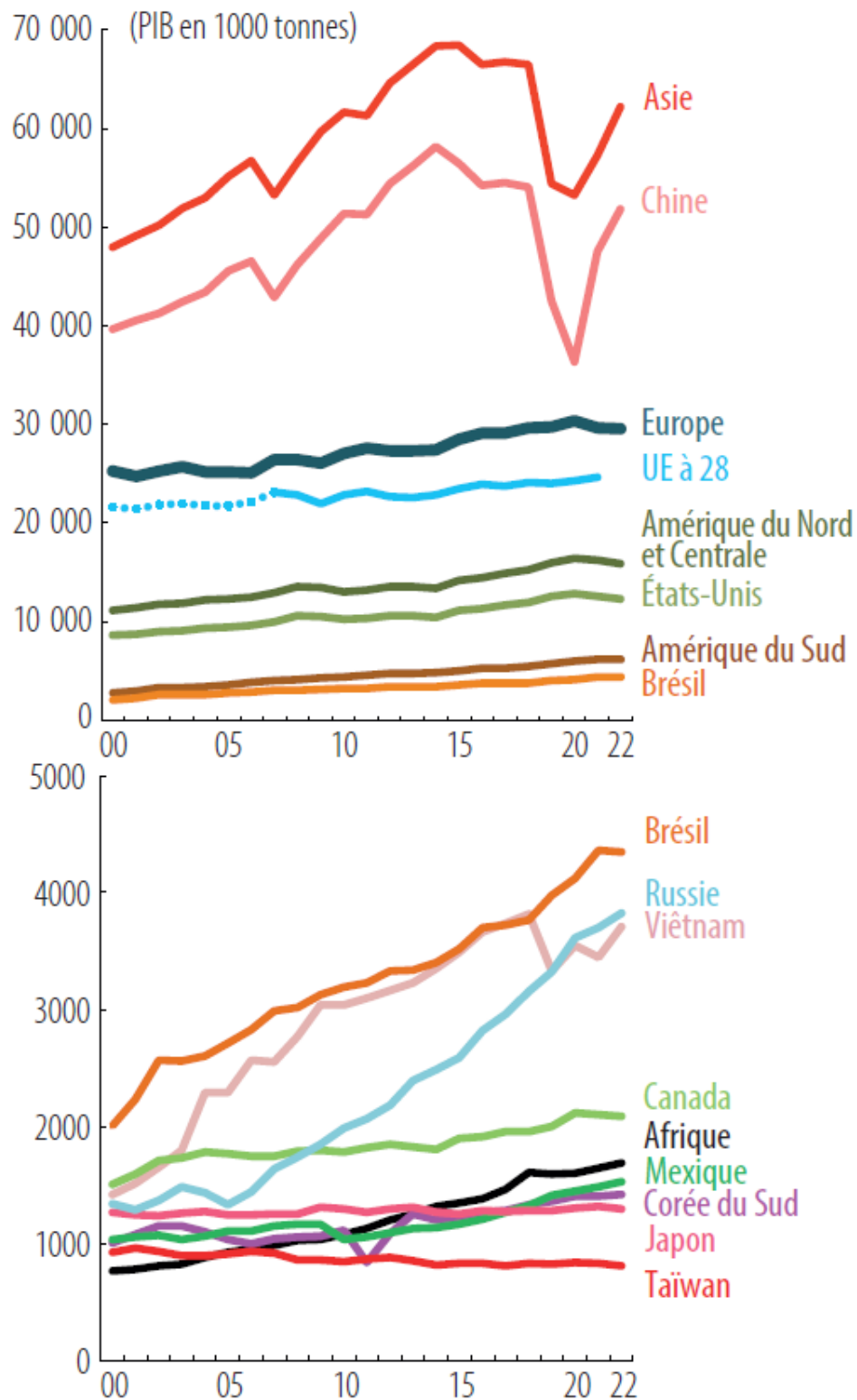


Figure 3. Evolution of global pork production (GDP in 1000 tons)

Pork Industry in the European

Union

The European pork industry faced a challenging year in 2022, marked by a decline in production and various economic pressures. The EU's pork production fell by approximately 5%, equating to a loss of over 12.6 million pigs for slaughter. Germany, historically one of the largest producers, saw a significant 10% reduction in output due to ongoing economic and sanitary crises. Spain, while typically a growing market, experienced its first production decline since 2014 due to increased piglet mortality rates from health issues.

Despite these challenges, some regions showed resilience. France managed a relatively smaller production decrease of 2%, maintaining its position as a key player in the European market. The economic environment, characterized by rising inflation and high feed costs, pushed pork prices to record levels across the continent, with French pork prices ranking high in Europe, just behind Spain.

The consumption patterns within the EU also varied significantly. Countries like Denmark and Spain exhibited high per capita pork consumption rates, while others like the United Kingdom and Italy showed more moderate consumption levels. This disparity reflects both cultural preferences and economic conditions across the region.

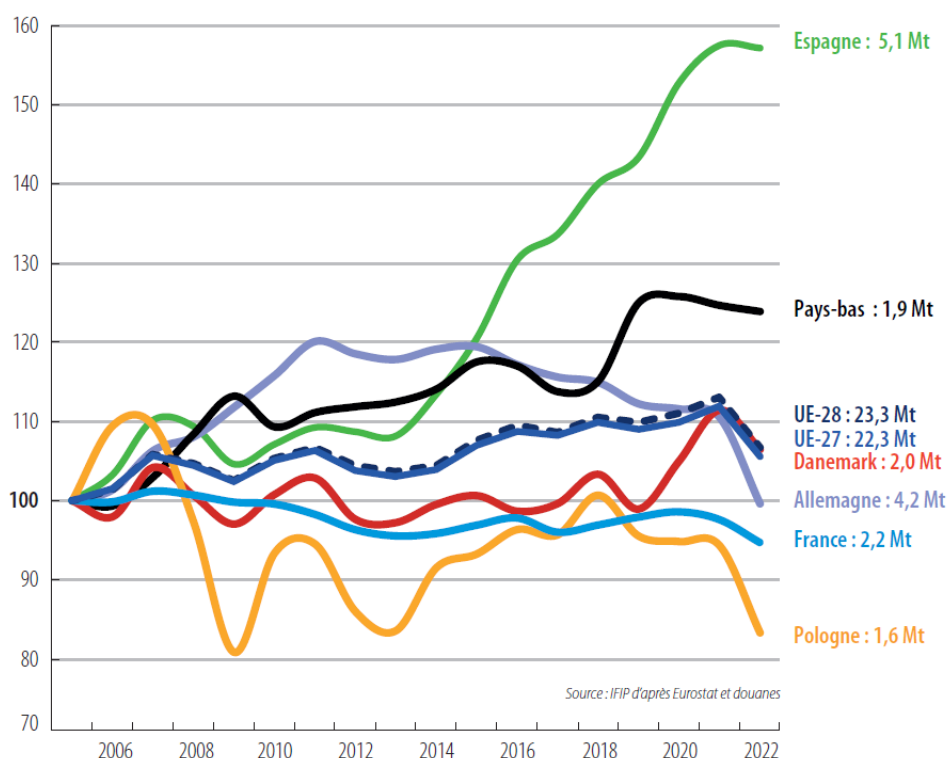


Figure 4. Evolution of pork production in the main EU countries (tons, from a base of 100 in 2005)

The French Pork Industry

In France, the pork industry in 2022 faced a year of significant adjustments. The country produced 2.19 million tons of carcass weight equivalent, a 3% decrease from the previous year. This decline was attributed to reduced slaughter weights and lower export volumes of live pigs. Despite these challenges, France remained the third-largest pork producer in the EU, following Spain and Germany.

Regionally, pork production is concentrated in areas like Brittany and Pays de la Loire. Brittany alone accounts for a substantial portion of the national production. The distribution of pork farms across France highlights the regional specialization, with significant variations in production volumes from one region to another.

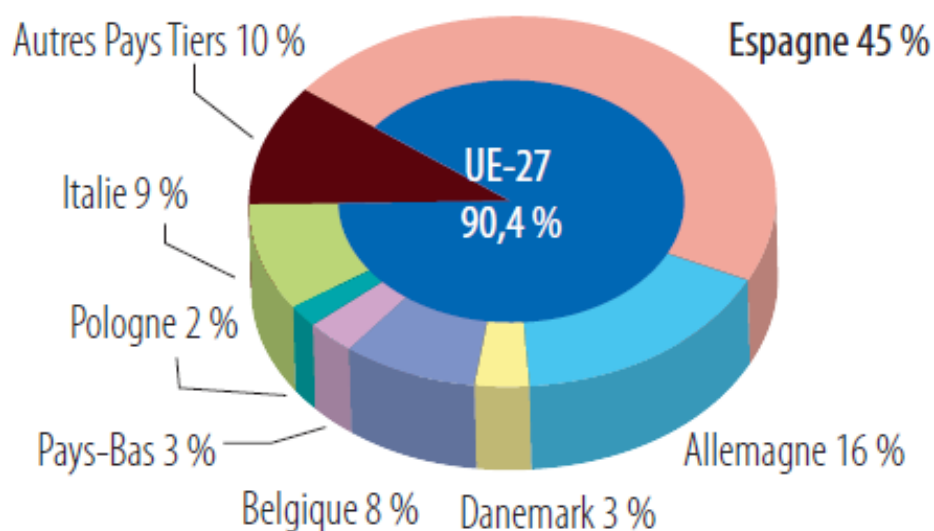


Figure 5. Suppliers to France (percentage of total imports)

French pork exports faced hurdles due to reduced demand from China, which saw a 35% drop in imports from France in 2022. However, increased sales to other Asian markets like the Philippines and Japan partially offset this decline. In terms of value, the higher pork prices helped mitigate the impact of lower export volumes, with total export values reaching 1.76 billion euros.

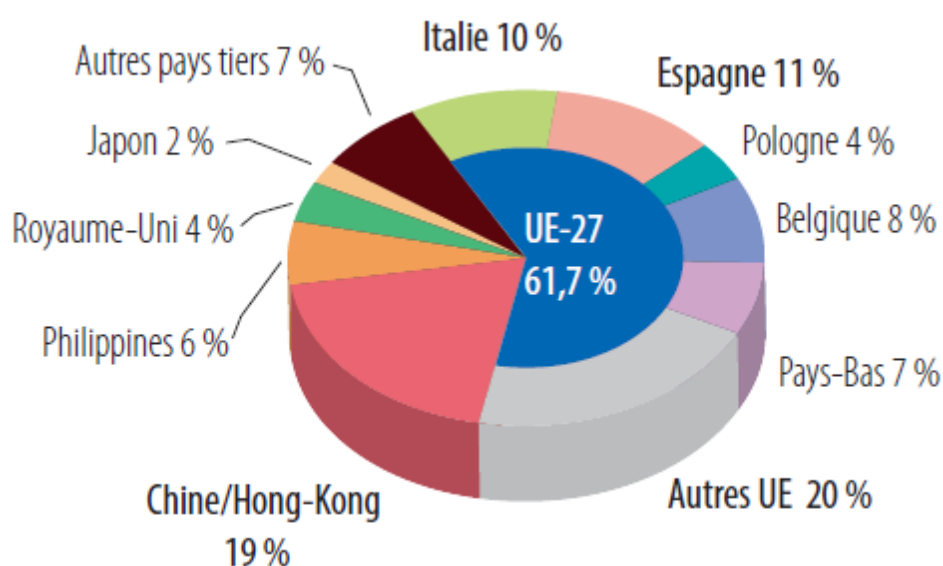


Figure 6. Export targets for France (percentage of total exports)

Economic and Production Challenges

The pork industry globally and within the EU faces several ongoing challenges. Rising feed costs, largely driven by global commodity price increases, have significantly impacted production costs. In Europe, the economic downturn and ongoing health crises like ASF and PRRS (Porcine Reproductive and Respiratory Syndrome) continue to challenge producers.

In France, inflation and high production costs have led to a tightening of profit margins for pig farmers. The high costs of feed and energy, coupled with lower production volumes, have made it difficult for many producers to remain profitable. The industry has responded with efforts to improve efficiency and sustainability, though these measures take time to implement and yield results.

Future Outlook

In Asia, China's recovery from ASF will likely stabilize, but the focus will shift towards improving biosecurity and production efficiency. In Europe, the industry will need to navigate economic challenges and health crises while adapting to changing consumer preferences towards more sustainable and ethical production practices.

For France, the key to future success will lie in balancing production efficiency with market demands. Investments in technology, biosecurity, and sustainable practices will be crucial. Additionally, expanding export markets beyond traditional partners will help mitigate the risks associated with market fluctuations.

The pork industry, both globally and within the EU, is at a pivotal point. The combination of economic pressures, health challenges, and shifting market dynamics necessitates strategic adjustments. By focusing on efficiency, sustainability, and market diversification, the industry can navigate these challenges and continue to thrive in the coming years.

The report can be read in full [here](#).

Oxidative & Inflammatory stress in reproductive Sows



By Dr. Inge Heinzl, Editor and Technical Team, EW Nutrition

One of the biggest challenges in swine production is keeping the modern, hyperprolific sow healthy and in good shape so that she can wean large, healthy litters and maintain her high reproductive performance.

Unfortunately, sows often suffer from stress and increased systemic inflammation around farrowing and during lactation. This leads to impaired feed intake and disturbed endocrine homeostasis, negatively affecting reproductive and litter performance.

The key to increasing the efficiency of pig production is to reduce the metabolic burden of sows while maintaining the reproductive performance of high-yield sows. A deep understanding of the complex interplay between environmental factors, sow well-being, health, and productivity is necessary to implement enhanced nutritional regimens and meticulous management practices.

Why does oxidative stress occur in today's sows?

Nowadays, hyperprolific sows produce between 30 and 40 weaned piglets per year and are at a higher risk of suffering from stress. What are the reasons?

A high number of piglets causes oxidative stress

Oxidative stress occurs when reactive oxygen species (ROS) are produced faster than the body's antioxidant mechanisms can neutralize them and cause damage to lipids, proteins, and DNA. During gestation, the sow needs high amounts of energy to provide for the fetuses. This energy is produced in the placental mitochondria. The placenta, therefore, is a place of active oxygen metabolism during gestation and a source of oxidative stress. In hyperprolific sows, a higher number of fetuses need even more energy to grow. Consequently, ROS production and the risk for intrauterine growth retardation (IUGR) increases (Figure 1). Moreover, evidence shows that the body's antioxidant potential is reduced in late gestation and after parturition ([Szczubial, 2010](#)), resulting in increased oxidative stress biomarkers ([Yang, 2023](#)). Increased milk production for large litters demands a substantial amount of energy, risking similar oxidative distress. Therefore, both the final phase of gestation and the subsequent lactation period are predestined for oxidative stress, which has been demonstrated by reduced TEAC (Trolox equivalent antioxidant capacity) levels during these phases ([Lee et al., 2023](#)).

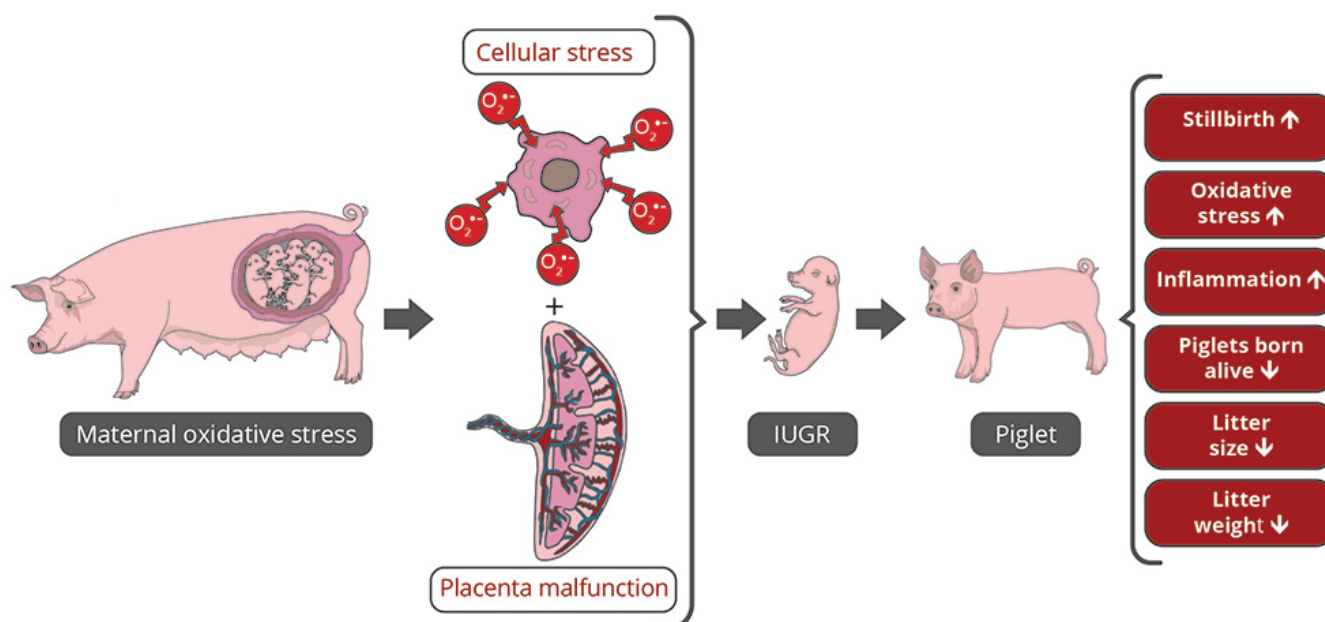


Figure 1. Illustration of the effect of oxidative stress on the fetus: intrauterine growth retardation (IUGR) (adapted from Yang et al., 2023)

Heat and ambient stress also contribute

The reproductive sow produces lots of heat. From the beginning of gestation, the sow's thermoneutral zone decreases. This, however, does not always correspond with the ambient conditions. Especially during the last days of gestation, the discrepancy is exceptionally high as everything is prepared for the newborn piglets, which need a temperature of about 27-35°C. The sow, on the contrary, would be happy with 18-22°C. Additionally, changes around farrowing – moving to the farrowing unit, social stress, change of feed, and the preparation for parturition – exert additional stress for the sows.

Why does the inflammation level increase?

After parturition, systemic inflammation is a normal phenomenon: the reproductive organs have sustained injuries during the parturition process and require remodeling. Inflammation is a natural and desired process, to repair the tissues and return to a normal status. However, inflammation is increased in modern sows, adversely affecting their inflammatory balance. Some possible underlying reasons are:

1. The high numbers of piglets need a lot of space in the uterus, often leading to damage of the uterine tissue and an inflammatory response in the sows. [Lee et al. \(2023\)](#) found significantly ($p < 0.10$) higher TNF- α concentrations in sows with litters of 15-20 piglets than in sows with 7-14 piglets. TNF- α is a biomarker of inflammation.
2. Pathogenic infections – particularly infections of the reproductive tract – can induce a prolonged or excessive inflammatory state. A further reason can be the need for more obstetric interventions in hyperprolific sows, which can injure the birth canal or the uterus.
3. Imbalanced nutrition: Excessive backfat is associated with a higher expression of proinflammatory cytokines, and feed contaminated with mycotoxins can impair the sow's immunocompetence.

Biomarkers can inform us about the oxidative status

Biomarkers are naturally occurring molecules that help us identify diseases or physiological processes. They provide insights into the oxidative state and inflammatory processes.

Anti-oxidative biomarkers

To check the anti-oxidative capacity, the “beneficial” substances, or antioxidants, can be quantified. These substances can neutralize free radicals or be neutralized by them. Higher levels of antioxidants indicate better antioxidant capacity; when antioxidants are abundant, fewer oxidizable substances have undergone oxidation.

Examples of antioxidant biomarkers:

Total Antioxidant Capacity (T-AOC): represents the synergistic interaction effects of all antioxidants in a matrix (E.g., diet or body fluids). It's a global measure of non-enzymatic antioxidant efficiency. Various assays, like **Trolox Equivalent Antioxidant Capacity (TEAC)**, which measures a substance's antioxidant capacity compared to Trolox, can measure T-AOC.

Glutathione Peroxidase (GSH-Px) belongs to the peroxidase family and converts hydrogen peroxide to water.

Catalase (CAT): scavenges ROS. Its activity can predict oxidative stress.

Superoxide Dismutase (SOD): catalyzes the dismutation of superoxide radicals to oxygen and hydrogen peroxide.

Oxidative biomarkers

Oxidative stress biomarkers, the ‘negative’ substances, can also serve as general biomarkers. These include free radicals with oxidant capacity or intermediate/final oxidation products. Ideally, their levels should be minimized.

Examples of oxidative stress biomarkers:

Thiobarbituric acid reactive substances (TBARS): to measure lipid peroxidation products in cells, tissues, and body fluids.

Reactive oxygen species (ROS) or free radicals: unstable, oxygen-containing molecules that react with other molecules in a cell. They might damage DNA, RNA, and proteins and cause cell death.

Hydrogen Peroxide (H₂O₂) is a ROS produced during normal cellular metabolism, which causes oxidative damage at excessive levels.

Malondialdehyde (MDA): a final product of oxidative fat degradation and, therefore, a biomarker for lipid peroxidation.

Pro-inflammatory biomarkers

Like oxidative stress, the interplay between pro- and anti-inflammatory signals helps develop the proper immune response for the appropriate duration.

Examples of Pro-inflammatory biomarkers or molecules produced in the case of inflammation:

- **Plasma Adenosine Deaminase (ADA-1 and ADA-2):** involved in immune regulation, with ADA-1 inhibiting pro-inflammatory responses and ADA-2 supporting immune cell functions.

- **Interleukins (IL-1 α and IL-1 β), IL-6:** IL-1 α and IL-1 β are associated with inflammatory diseases, IL-6: is produced during inflammation and acute-phase response.
- **Tumor Necrosis Factor α (TNF- α):** endogenous pyrogen that induces fever and promotes inflammation.
- **C-reactive Protein (CRP):** liver-produced acute-phase protein responding to inflammation.

Procalcitonin (PCT) is produced by the liver during infections and helps detect bacterial infections.

Examples of anti-inflammatory substances – the “good ones”:

- **Interleukines - IL-4, IL-10:** inhibit the function of the macrophages and act, therefore, anti-inflammatory
- **Cortisol:** anti-inflammatory and immune-suppressive
- **ACTH:** stimulates the production and release of cortisol

Higher stress or infection level lowers performance in sows and piglets

As mentioned, hyperprolific sows suffer from higher oxidative stress, especially during late gestation, parturition, and lactation. Additionally, systemic inflammation occurs to repair the injured tissues to facilitate the healing of the birth canal and remodeling of the uterus to establish the subsequent pregnancy. To this purpose, an inflammatory cascade, triggered by the injuries due to gestation and parturition, involves the release of critical (pro-inflammatory) mediators such as TNF- α and IL-6, leading to the activation of acute phase proteins.

After triggering inflammatory pathways, anti-inflammatory pathways must also be activated to reestablish homeostasis in the reproductive organs ([Serhan & Chiang, 2008](#)). Alterations at the onset of anti-inflammatory pathways and exacerbated activation and maintenance of inflammatory pathways can lead to uncontrolled inflammation and the onset of reproductive disease in sows ([Kaiser et al., 2018](#)), as well as reduced feed intake and insufficient milk production, resulting in poorly growing piglets and lower weaning weights or piglets suffering from clinical infectious diseases such as diarrhea. If possibly homeostasis cannot be restored, the sow is at risk of contracting diseases like post-partum dysgalactia syndrome (PPDS), lameness, and impaired fertility.

Targeted use of polyphenols can mitigate inflammation and improve the oxidative status of sows

There are several experiments showing the beneficial effects of natural compounds. Especially polyphenols, disposing of phenyl rings and two or more hydroxyl substituents, are perfect radical scavengers and proven antioxidants ([Chen, 2023](#)). Phytogetic substances that have anti-inflammatory effects can be found in the families of polyphenols as well as terpenoids, flavonoids, saponins, and tannins ([Bunte et al., 2019](#); [Ge et al., 2022](#); [Ginwala et al., 2019](#); [Santos Passos et al., 2022](#); [Ambreen and Mirza, 2020](#)).

Here are some examples showing the beneficial effects of phytochemicals:

1. Primiparous sows fed with *Moringa oleifera* leaf meal, rich in polyphenols, saponins, and tannins, illustrate the potential of phytomolecules: serum levels of T-AOC (total anti-oxidative capacity), were increased in late gestation and during lactation, while MDA was reduced. Additionally, piglets that received *Moringa oleifera* meal showed the highest serum CAT and SOD activities. The meal significantly decreased the farrowing length and number of stillbirths, while there was an increasing trend in the number of live-born piglets ([Sun et al., 2020](#)).

2. The polyphenol Daidzein, a member of the class of compounds known as isoflavones (200 mg/kg during gestation), increased the total antioxidant capacity (T-AOC) and the activities of glutathione peroxidase and superoxide dismutase. Additionally, it elevated the level of immunoglobulin G and increased the number of piglets born and born alive per litter ([Li et al., 2021](#)).
3. Glycitein, a polyphenol occurring in the isoflavone fraction of soy products, applied during late gestation and lactation increased the total antioxidant capacity and SOD activity during the first 18 days of lactation and the CAT and GSH-Px activity in mid-lactation. Plasma MDA level was reduced from late gestation to the 18th day of lactation. The enhanced oxidative status of the sow resulted in a higher daily gain of the piglets and a higher weaning weight of the litter ([Hu et al., 2015](#)).
4. [Meng et al. \(2018\)](#) tested Resveratrol (300 mg/kg), a stilbenes polyphenol, in sows from day 20 of gestation until farrowing. They saw noticeably higher GSH-Px, SOD, and CAT activities, as well as lower contents of MDA and H₂O₂ in the placental tissue, improving the antioxidant status of sows and piglets.
5. [Xu et al. \(2022\)](#) fed silymarin to sows in late gestation. They observed that IL-1 β concentration in the blood sample on the 18th day of lactation was reduced in the supplemented group. The altered fecal microbiota was associated with variations in inflammatory factors, suggesting that silymarin modulates microbiota in the gut and may improve the health of lactation sow.

Phytochemicals support sows against oxidative and inflammatory stress

The above-presented examples show that phytochemicals, particularly those developed to have a potent anti-inflammatory and anti-oxidative capacity, have a high potential to alleviate oxidative stress in pregnant and lactating sows and reduce inflammation when applied in sow diets. Consequently, a broader use of these natural substances should be considered to reduce the metabolic burden of sows and increase the efficiency of pig production.

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Unlocking Optimum Poultry Performance: Harnessing the

Power of GH10 Xylanase



Author: Ajay Bhojar, Global Technical Manager, EW Nutrition

Exogenous feed enzymes are increasingly utilized in poultry diets to manage feed costs, mitigate the adverse effects of anti-nutritional factors, and enhance nutrient digestion and bird performance. These enzymes are primarily employed to bolster the availability of nutrients within feed ingredients. Among the various enzymes utilized, those capable of breaking down crude fiber, starch, proteins, and phytates are commonly integrated into animal production systems.

In monogastric animals such as poultry and swine, a notable deficiency exists in the endogenous synthesis of enzymes necessary for the hydrolysis of non-starch polysaccharides (NSPs) like xylan ([McLoughlin et al., 2017](#)). This deficiency often manifests in poultry production as a decline in growth performance, attributed to increased digesta viscosity arising from the prevalence of NSPs in commonly utilized poultry feed ingredients. Without sufficient endogenous enzymes to degrade xylan, NSPs can increase digesta viscosity, encase essential nutrients, and create a barrier to their effective digestion. In response to this issue, monogastric animal producers have implemented exogenous enzymes such as xylanases into the feeds for swine and poultry to degrade xylan to short-chain sugars, thus reducing intestinal viscosity and improving the digestive utilization of nutrients ([Sakata et al., 1995](#); [Aragon et al., 2018](#))

Understanding Xylanase Enzymes

Xylanase enzymes belong to the class of carbohydrases that specifically target complex polysaccharides, such as xylan, a backbone nonstarch polysaccharide (NSP) prevalent in plant cell walls. These enzymes catalyze the hydrolysis of xylan into smaller, more digestible fragments, such as arabino-xylo-oligosaccharides (AXOs) and xylo-oligosaccharides (XOs), thereby facilitating the breakdown of dietary fiber in poultry diets.

Mechanism of action

It is generally agreed that the beneficial effects of feed xylanase are primarily due to the reduction in viscosity. Studies have shown that supplementing xylanases to animal feeds reduces digesta viscosity and releases encapsulated nutrients, thus improving the overall feed digestibility and nutrient availability ([Matthiesen et al., 2021](#)). The reduction in digesta viscosity by adding xylanase is achieved by the partial hydrolysis of NSPs in the upper digestive tract, leading to a decrease in digesta viscosity in the small intestine ([Choct & Annison, 1992](#)).

GH10 vs. GH11 Xylanases

Well-characterized xylanases are mostly grouped into glycoside hydrolase families 10 (GH10) and 11 (GH11) based on their structural characteristics (amino acid composition), mode of xylan degradation, the similarity of catalytic domains, substrate specificities, optimal conditions, thermostability, and practical applications.

Why are GH10 xylanases more efficient in animal production?

While both GH10 and GH11 xylanases act on the xylan main chain, these two enzyme types have different folds, substrate specificities, and mechanisms of action ([Biely et al., 2016](#)). The GH10 xylanases are more beneficial in animal feed production due to their efficient mechanism of action, broader substrate specificity, and better thermostability, as discussed below.

GH10 xylanase exhibits broader substrate specificity

Generally, the GH10 xylanases exhibit broader substrate specificity and can hydrolyze various forms of xylan, including soluble and insoluble substrates. On the other hand, GH11 xylanases have a narrower substrate specificity and are primarily active on soluble xylan substrates. GH10 xylanases exhibit higher catalytic versatility and can catalyze the cleavage of the xylan backbone at the nonreducing side of substituted xylose residues, whereas GH11 enzymes require unsubstituted regions of the xylan backbone ([Collins et al., 2005](#); [Chakdar et al., 2016](#)).

As a result, GH10 xylanases generally produce shorter xylo-oligosaccharides than members of the GH11 family ([Collins et al., 2005](#)). Moreover, as shown in Fig.1, the GH10 xylanase can rapidly and effectively break down xylan molecules.

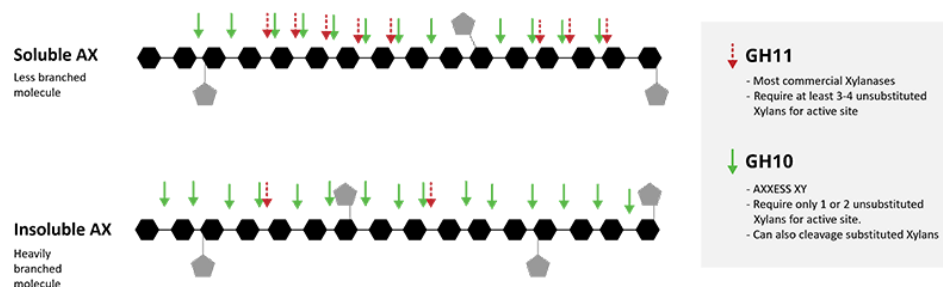


Fig.1.: Activity of a bacterial GH10 xylanase against soluble and insoluble arabinoxylans

Higher thermostability

Enzymes are proteins, and the protein's primary structure determines their thermostability. The enzyme protein tends to denature at higher than tolerable temperatures, rendering it inactive. An enzyme's high-temperature tolerance ensures its efficacy throughout the pelleted feed manufacturing. This results in consistent enzyme activity in the finished feed, subsequent gut health, and predictable performance benefits.

Xylanases with higher thermostability are more suitable for applications requiring high-temperature processes. An intrinsically heat-stable bacterial xylanase maintains its activity even under high-temperature feed processing conditions, such as pelleting.

A study conducted at the University of Novi Sad, Serbia (Fig. 2), with three pelleting temperatures (85 °C, 90 °C, and 95 °C) and conditioning times of 4 and 6 mins, showed that Axxess XY, an intrinsically thermostable GH10 xylanase, demonstrated more than 85% recovery even at 4 to 6 mins conditioning time and 95 °C temperature.

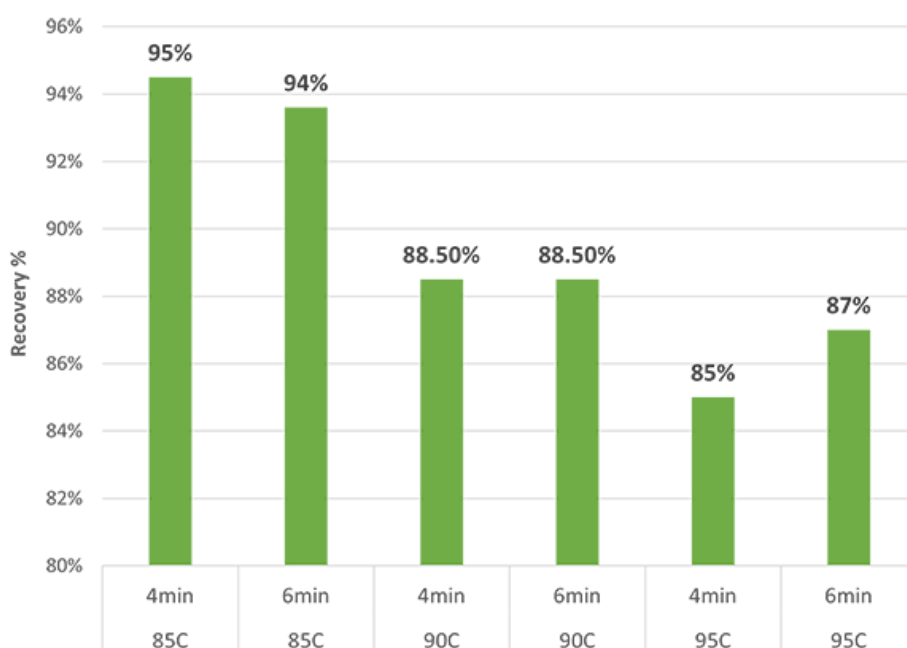


Fig.2: Optimum recovery of Axxess XY at elevated conditioning time and temperatures

Maintaining consistently optimum enzyme activity is crucial for realizing the benefits of enzyme inclusion in feed under challenging feed processing conditions.

Conclusion

In conclusion, exogenous feed enzymes, including xylanase, have gained widespread recognition for their pivotal role in poultry nutrition. The increasing use of xylanase is attributed to its ability to effectively manage feed costs while incorporating high-fiber ingredients without compromising poultry performance. However, the efficacy of xylanase is based on several factors, including its mode of action, substrate specificity, catalytic efficacy, and thermostability. Selecting the appropriate xylanase enzyme tailored for specific needs is crucial to harnessing its full benefits.

A GH10 xylanase, such as Axxess XY, designed explicitly as a feed enzyme, offers distinct advantages in poultry production. Its efficient mechanism of action, broader substrate specificity, and superior thermostability make it a preferred choice for optimizing animal performance. Notably, Axxess XY exhibits exceptional activity against soluble and insoluble arabinoxylans, thereby enhancing nutrient utilization, promoting gut health, and ultimately elevating overall performance levels in poultry.

Incorporating specialized GH10 Xylanase enzymes like Axxess XY represents a strategic approach to

unlocking the nutrients in feedstuffs, ensuring optimal performance, and maximizing profitability in the poultry business.

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Overcoming Challenges of Xylanase Inhibitors in Animal Feeds



By Dr. Ajay Awati, Global Director Enzymes, EW Nutrition

In recent years, the scientific understanding of xylanase inhibitors (XIs) and their impact on animal nutrition has grown significantly. Xylanase, a crucial enzyme used to enhance nutrient availability in feed, can face challenges from XIs present in cereal grains. This article explores the evolution of plant protection mechanisms, the economic impact of XIs, and the development of a novel xylanase, Axxess XY, resistant to these inhibitors.

Xylanase inhibitors - an evolutionary protection mechanism of plants

Xylanase inhibitors (XI) are a classic example of the evolutionary development of protection mechanisms by cereal plants against pathogens. Microorganisms, such as fungal pathogens, involve the degradation of xylan as one of the mechanisms in pathogenesis (Choquer et al., 2007). There are also other mechanisms by which microorganism-produced xylanases affect plants.

To protect themselves, plants evolved xylanase inhibitors to prevent the activities of xylanases. XIs are plant cell wall proteins broadly distributed in monocots. There are three classes of XIs with different structures and inhibition specificities (Tundo et al., 2022):

1. Triticum aestivum xylanase inhibitors (TAXI)
2. Xylanase inhibitor proteins (XIP), and
3. Thaumatin-like xylanase inhibitors (TLXI).

Xylanase inhibitors have an economic

impact

In animal nutrition, xylanases are widely used in diets containing cereal grains and other plant materials to achieve a higher availability of nutrients. The inhibitory activity of XIs prevents this positive effect of the enzymes and, therefore, makes them economically relevant. Studies have reported that higher levels of XIs negatively impact broiler performance. For example, in one of the studies, broilers fed with grains of a cultivar with high inhibitory activity showed a 7% lower weight on day 14 than broilers fed with grains of a cultivar with less inhibitory activity (Madsen et al., 2018). Another study by Ponte et al. (2004) also concluded that durum wheat xylanase inhibitors reduced the activity of exogenous xylanase added to the broiler diets.

Xylanase inhibitors can withstand high temperatures

Even though XIs can impact the performance of exogenous xylanase in different ways, only minor attention was paid to the reduction of xylanase's susceptibility to xylanase inhibitors during the xylanase development in the last decades. Firstly, the issue was ignored mainly through the assumption that XIs are denatured or destroyed during pelleting processes. However, Smeets et al. (2014) showed that XIs could sustain significant temperature challenges. They demonstrated that after exposing wheat to pelleting temperatures of 80°C, 85°C, 92°C, and 95°C, the recovery of inhibitory activity was still 99%, 100%, 75%, and 54%, respectively. Furthermore, other studies also confirmed that conditioning feed at 70-90°C for 30 sec followed by pelleting had little effect on the XI activity in the tested feed, showing that xylanase inhibitors are very likely present in most xylanase-supplemented feeds fed to animals.

Do we only have the problem of xylanase inhibitors in wheat?

No. After first reports of the presence of xylanase inhibitors in wheat by Debyser et al. (1997, 1999), XIs were also found in other cereal grains (corn, rice, and sorghum, etc.), and their involvement in xylanase inhibition and plant defense has been established by several reports (Tundo et al., 2022).

In most of the countries outside Europe, exogenous xylanase is used not only in wheat but also in corn-based diets. Besides broiler feeds, also other animal feeds, such as layer or swine feed being part of more mixed-grain diets, are susceptible to the inhibitory activity of XIs. Nowadays, the situation is getting worse with all the raw material prices increasing and nutritionists tending to use other feed ingredients and locally produced cereals. They need a xylanase which is resistant to xylanase inhibitors.

Xylanases' resistance to XIs is crucial - Axxess XY shows it

To prevent xylanases from losing their effect due to the presence of xylanase inhibitors, the resistance of new-generation xylanases to these substances is paramount in the development process, including enzyme discovery and engineering.

In the past 25 years, scientists have learned much about XI-encoding genes and discovered how xylanase inhibitors can block microbial xylanases. Additionally, there has been a significant increase in understanding the structural aspects of the interaction between xylanases and XIs, mainly how xylanase inhibitors interact with specific xylanases from fungi or bacteria and those in the GH10 or GH11 family. With such understanding, a new generation xylanase, Axxess XY, was developed. Besides showing the

essential characteristics of intrinsic thermostability and versatile activity on both soluble and insoluble arabinoxylan, it is resistant to xylanase inhibitors.

Axxess XY takes xylanase application in animal feeds to the next level.

Axxess XY outperforms other xylanases on the market

Recent scientific developments (Fierens, 2007; Flatman et al., 2002; Debyser, 1999; Tundo et al., 2022; Chmelova, 2019) and internal research can be summarized as follows:

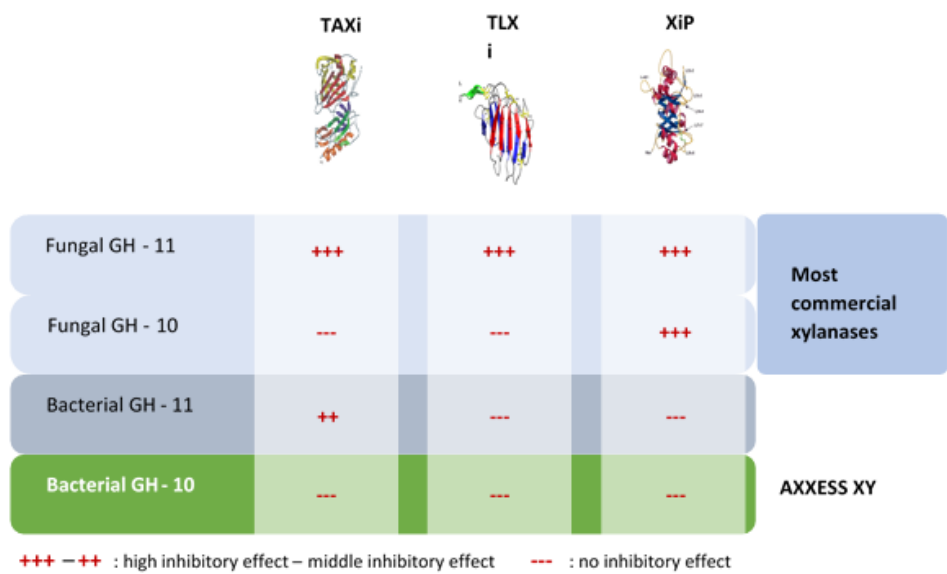


Figure 1: Schematic summary of the susceptibility of different xylanase to xylanase inhibitors from three main groups.

The high resistance to xylanase inhibitors is one of the reasons that a novel xylanase with bacterial origin and from the GH-10 family was chosen to be Axxess XY. EWN innovation, together with research partners, made an interesting benchmark comparison between xylanases that are commercially sold by different global suppliers and Axxess XY. For these trials, all xylanase inhibitors from wheat were extracted. The inhibitors, together with the respective xylanase, were incubated at 40 °C (to mimic birds' body temperature) for 30 mins. Then, the loss of xylanase activity was calculated by analyzing remaining activity after incubation. Results are shown below in Figure 2. There were varying levels of activity loss observed in the different commercially sold xylanases. In some xylanases, the losses were alarmingly high. However, Axxess XY was not inhibited at all.

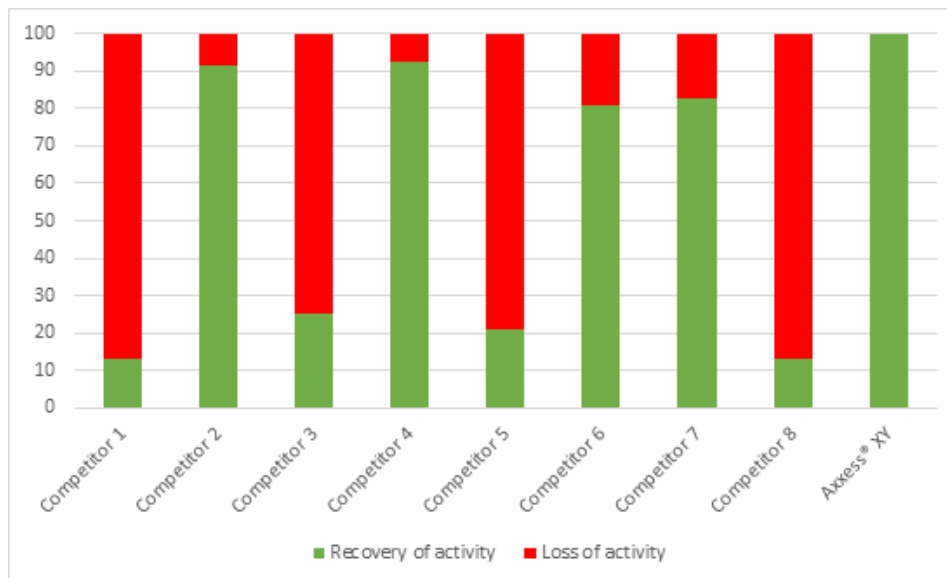


Fig. 2: Extracted total xylanase inhibitors from wheat incubated with the respective xylanase at 40°C for 30 mins. – Loss of activity after incubation with xylanase inhibitors

Conclusion:

Xylanase inhibitors are present in all cereal grains and, unfortunately, heat tolerant (up to 90°C, still 75% of inhibition activity was retained). Regardless of the diets used, there is a possibility that the xylanase used may come across xylanase inhibitors, resulting in a loss of activity. More importantly, this can lead to inconsistent performance.

For effective, consistent, and higher performance of NSP enzyme application, it is a must to use xylanase that is resistant to xylanase inhibitors.

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Organic acids can play a crucial

role in zinc oxide replacement



*Dr. Inge Heinzl, Editor EW Nutrition &
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The use of high levels of Zinc Oxide (ZnO) in the EU before 2022 was one of the most common methods to prevent postweaning diarrhea (PWD) in pig production. Pharmacologically high levels of ZnO (2000-3000 ppm) increase growth and reduce the incidence of enteric bacterial diseases such as post-weaning diarrhea (PWD) ([Carlson et al., 1999](#); [Hill et al., 2000](#); [Hill et al., 2001](#); [Poulsen & Larsen, 1995](#); [De Mille et al., 2019](#)).

However, ZnO showed adverse effects, such as the accumulation of heavy metal in the environment, the risk for antimicrobial resistance (AMR), and problems of mineral toxicity and adverse growth effects when feeding it longer than 28 days ([Jensen et al., 2018](#); [Cavaco et al., 2011](#); [Vahjen, 2015](#); [Romeo et al., 2014](#); [Burrough et al., 2019](#)). To replace ZnO in pig production, let us first look at its positive effects to know what we must compensate for.

ZnO has a multifactorial mode of action

ZnO shows several beneficial characteristics that positively influence gut health, the immune system, digestion, and, therefore, also overall health and growth performance.

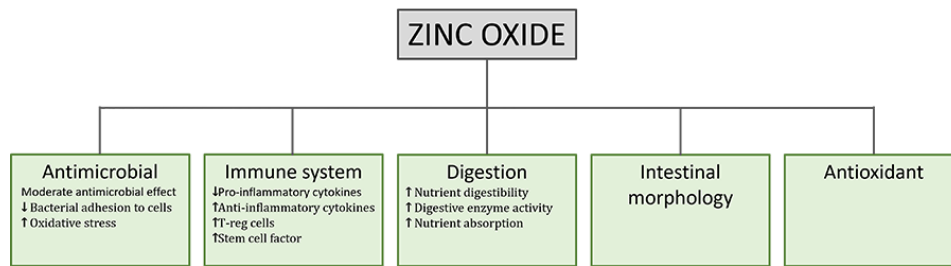


Figure 1. Beneficial effects and ZnO mode of action in postweaning piglets

1. ZnO acts as an antimicrobial

Concerning the antimicrobial effects of ZnO, different possible modes of action are discussed:

- ZnO in high dosages generates reactive oxygen species (ROS) that can damage the bacterial cell walls ([Pasquet et al., 2014](#))
- The death of the bacterial cell due to direct contact of the metallic Zn to the cell ([Shearier et al., 2016](#))
- Intrinsic antimicrobial properties of the ZnO^{2+} ions after dissociation. The uptake of zinc into cells is regulated by homeostasis. A concentration of the ZnO^{2+} ions higher than the optimal level of 10^{-7} to 10^{-5} M (depending on the microbial strain) allows the invasion of Zn^{2+} ions into the cell, and the zinc starts to be cytotoxic ([Sugarman, 1983](#); [Borovanský et al., 1989](#)).

ZnO shows activity against, e.g., *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *E. coli*, *Streptococcus pyogenes*, and other enterobacteria (Ann et al., 2014; Vahjen et al., 2016). However, Roselli et al. (2003) did not see a viability-decreasing effect of ZnO on ETEC.

2. ZnO modulates the immune system

Besides fighting pathogenic organisms as described in the previous chapter and supporting the immune system, ZnO is an essential trace element and has a vital role in the immune system. ZnO improves the innate immune response, increasing phagocytosis and oxidative bursts from macrophages and neutrophils. It also ameliorates the adaptative immune response by increasing the number of T lymphocytes (T cells) in general and regulatory T lymphocytes (T-regs) in particular. These cells control the immune response and inflammation ([Kloubert et al., 2018](#)). Macrophage capacity for phagocytosis ([Ercan and Bor, 1991](#)) and to kill parasites ([Wirth et al., 1989](#)), and also the killing activity of natural killer cells depends on Zn ([Rolles et al., 2018](#)). By reducing bacterial adhesion and blocking bacterial invasion, ZnO disburdens the immune system ([Roselli et al., 2003](#)).

ZnO reduces the expression of several proinflammatory cytokines induced by ETEC ([Roselli et al., 2003](#)). Several studies have also shown a modulation effect on intestinal inflammation, decreasing levels of IFN- γ , TNF- α , IL-1 β and IL-6, all pro-inflammatory, in piglets supplemented with ZnO ([Zhu et al., 2017](#); [Grilli et al., 2015](#)).

3. ZnO improves digestion and promotes growth

Besides protecting young piglets against diarrhea, the goal is to make them grow optimally. For this target, an efficient digestion and a high absorption of nutrients is essential. Stimulating diverse pancreatic enzymes such as amylase, carboxypeptidase A, trypsin, chymotrypsin, and lipase increases digestibility ([Hedemann et al., 2006](#); [Pieper et al., 2015](#)). However, Pieper et al. (2015) also showed that a long-term supply of very high dietary zinc triggers oxidative stress in the pancreas of piglets.

By stimulating the secretion of ghrelin at the stomach level and thereby promoting the release of insulin-like growth factor (IGF-1) and cholecystokinin (CCK), ZnO enhances muscle protein synthesis, cell

proliferation, and feed intake ([Yin et al., 2009](#); [MacDonald et al., 2000](#))).

The result of improved digestion is increased body weight and average daily gain, which can be seen, e.g., in a study by [Zhu et al. \(2017\)](#).

4. ZnO protects the intestinal morphology

ZnO prevents the decrease of the trans-endothelial electrical resistance (TEER), usually occurring in the case of inflammation, by downregulating TNF- α and IFN- γ . TNF- α , as well as IFN- γ , increase the permeability of the epithelial tight junctions and, therefore, the intestinal barrier ([Al-Sadi et al., 2009](#)).

The enterotrophic and anti-apoptotic effect of ZnO is reflected by a higher number of proliferating and PCNA-positive cells and an increased mucosa surface in the ileum (higher villi, higher villi/crypt ratio) ([Grilli et al., 2015](#)). [Zhu et al. \(2017\)](#) also saw an increase in villus height in the duodenum and ileum and a decrease in crypt depth in the duodenum due to the application of 3000 mg of ZnO/kg. Additionally, they could notice a significant ($P < 0.05$) upregulation of the mRNA expression of the zonula occludens-1 and occluding in the mucosa of the jejunum of weaned piglets.

In a trial conducted by [Roselli et al. \(2003\)](#), the supplementation of 0.2 mmol/L ZnO prevented the disruption of the membrane integrity when human Caco-2 enterocytes were challenged with ETEC.

5. ZnO acts antioxidant

The antioxidant effect of ZnO was shown in a study conducted by [Zhu et al., 2017](#). They could demonstrate that the concentration of malondialdehyde (MDA), a marker for lipid peroxidation, decreased on day 14 or 28, and the total concentration of superoxide dismutase (SOD), comprising enzymes that transform harmful superoxide anions into hydrogen peroxide, increased on day 14 ($P < 0.05$). Additionally, Zn is an essential ion for the catalytic action of these enzymes.

Which positive effects of ZnO can be covered by organic acids (OAs)?

1. OAs act antimicrobial

OAs, on the one hand, lower the pH in the gastrointestinal tract. Some pathogenic bacteria are susceptible to low pH. At a $\text{pH} < 5$, the proliferation of, e.g., Salmonella, E. coli, and Clostridium is minimized. The good thing is that some beneficial bacteria, such as lactobacilli or bifidobacteria, survive as they are acid-tolerant. The lactobacilli, on their side, can produce hydrogen peroxide, which inhibits, e.g., Staphylococcus aureus or Pseudomonas spp. ([Juven and Pierson, 1996](#)).

Besides this more indirect mode of action, a more direct one is also possible: Owing to their lipophilic character, the undissociated form of OAs can pass the bacterial membrane ([Partanen and Mroz, 1999](#)). The lower the external pH, the more undissociated acid is available for invading the microbial cells. Inside the cell, the pH is higher than outside, and the OA dissociates. The release of hydrogen ions leads to a decrease in the internal pH of the cell and to a depressed cell metabolism. To get back to “normal conditions”, the cell expels protons. However, this is an energy-consuming process; longer exposure to OAs leads to cell death. The anion remaining in the cell, when removing the protons, disturbs the cell's metabolic processes and participates in killing the bacterium.

These theoretical effects could be shown in a practical trial by [Ahmed et al. \(2014\)](#). He fed citric acid (0.5 %) and a blend of acidifiers composed of formic, propionic, lactic, and phosphoric acid + SiO_2 (0.4 %) and saw a reduction in fecal counts of Salmonella and E. coli for both groups.

2. OAs modulate the immune system

The immune system is essential in the pig's life, especially around weaning. Organic acids have been shown to support or stimulate the immune system. Citric acid (0.5%), as well as the blend of acidifiers mentioned before (Ahmed et al., 2014), significantly increased the level of serum IgG. IgG is part of the humoral immune system. They mark foreign substances to be eliminated by other defense systems.

[Ren et al.](#) (2019) could demonstrate a decrease in plasma tumor necrosis factor- α that regulates the activity of diverse immune cells. He also found lower interferon- γ and interleukin (IL)-1 β values in the OA group than in the control group after the challenge with ETEC. This trial shows that inflammatory response can be mitigated through the addition of organic acids.

3. OAs improve digestion and promote growth

In piglets, the acidity in the stomach is responsible for the activation and stimulation of certain enzymes. Additionally, it keeps the feed in the stomach for a longer time. Both effects lead to better digestion of the feed.

In the stomach, the conversion of pepsinogen to pepsin, which is responsible for protein digestion, is catalyzed under acid conditions ([Sanny et al., 1975](#)) group. Pepsin works optimally at two pH levels: pH 2 and pH 3.5 ([Taylor, 1959](#)). With increasing pH, the activity decreases; at pH 6, it stops. Therefore, a high pH can lead to poor digestion and undigested protein arriving in the intestine.

These final products of pepsin protein digestion are needed in the lower parts of the GIT to stimulate the secretion of pancreatic proteolytic enzymes. If they do not arrive, the enzymes are not activated, and the inadequate protein digestion continues. Additionally, gastric acid is the primary stimulant for bicarbonate secretion in the pancreas, neutralizing gastric acid and providing an optimal pH environment for the digestive enzymes working in the duodenum.

As already mentioned, the pH in the stomach influences the transport of digesta. The amount of digesta being transferred from the stomach to the small intestine is related to the acidity of the chyme leaving the stomach and arriving in the small intestine. Emptying of the stomach can only take place when the duodenal chyme can be neutralized by pancreatic or other secretions ([Pohl et al., 2008](#)); so, acid-sensitive receptors provide feedback regulation and a higher pH in the stomach leads to a faster transport of the digesta and a worse feed digestion.

4. OAs protect the intestinal morphology

Maintaining an intact gut mucosa with a high surface area is crucial for optimal nutrient absorption. Research suggests organic acids play a significant role in improving mucosal health:

Butyric acid promotes epithelial cell proliferation, as demonstrated in an *in vitro* pig hindgut mucosa study ([Sakata et al., 1995](#)). Fumaric acid, serving as an energy source, may locally enhance small intestinal mucosal growth, aiding in post-weaning epithelial cells' recovery and increasing absorptive surface and digestive capacity ([Blank et al., 1999](#)). Sodium butyrate supplementation at low doses influences gastric morphology and function, thickening the stomach mucosa and enhancing mucosal maturation and differentiation ([Mazzoni et al., 2008](#)).

Studies show that organic acids affect gut morphology, with a mixture of short-chain and mid-chain fatty acids leading to longer villi ([Ferrara et al., 2016](#)) and Na-butyrate supplementation increasing crypt depth and villi length in the distal jejunum and ileum ([Kotunia et al., 2004](#)). However, the villi length and mucosa thickness in the duodenum were reduced. Dietary sodium butyrate has been linked to increased microvilli length and cecal crypt depth in pigs ([Gálfi and Bokori, 1990](#)).

5. OAs show antioxidant activity

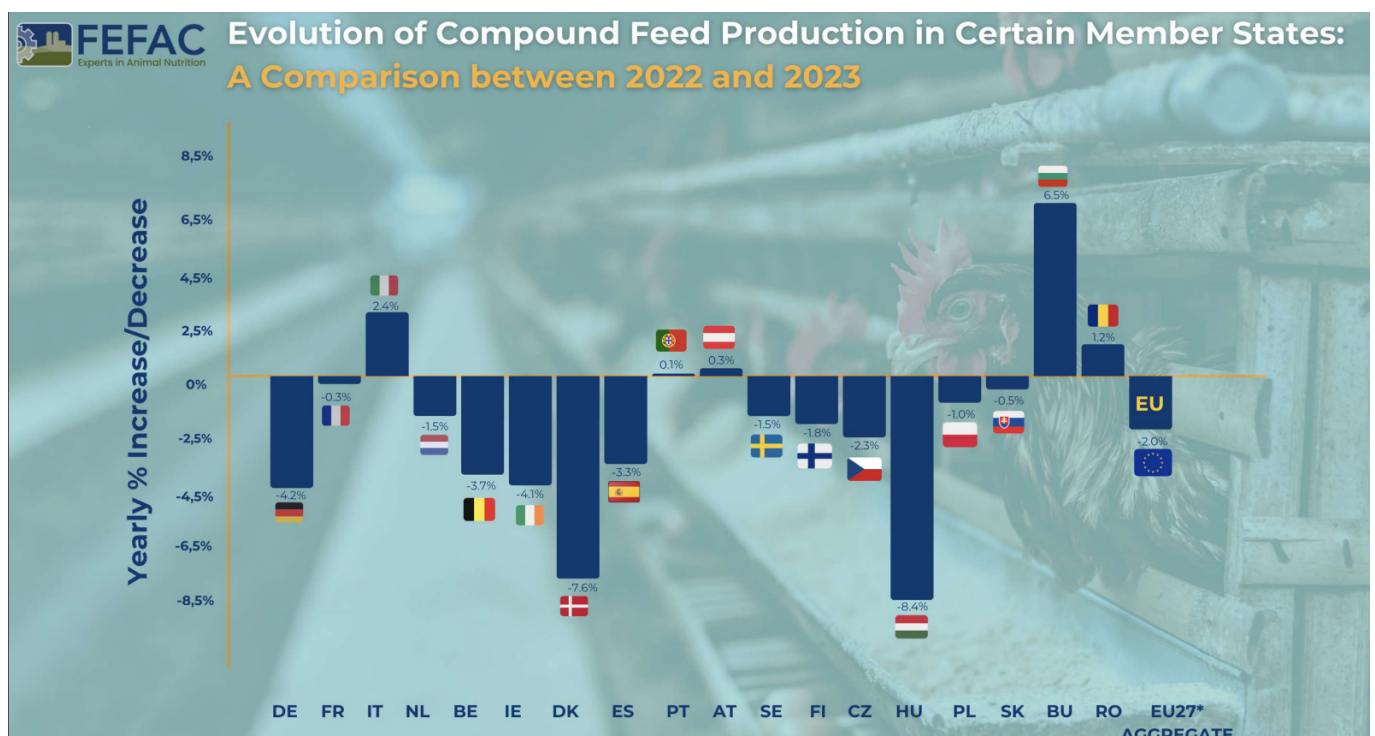
The last characteristic, the antioxidant effect, cannot be provided at the same level as with ZnO; however, [Zhang et al. \(2019\)](#) attest to OAs a certain antioxidant activity. Oxalic, citric, acetic, malic, and succinic acids, which were extracted from *Camellia oleifera*, also showed good antioxidant activity in a trial conducted by [Zhang et al. \(2020\)](#).

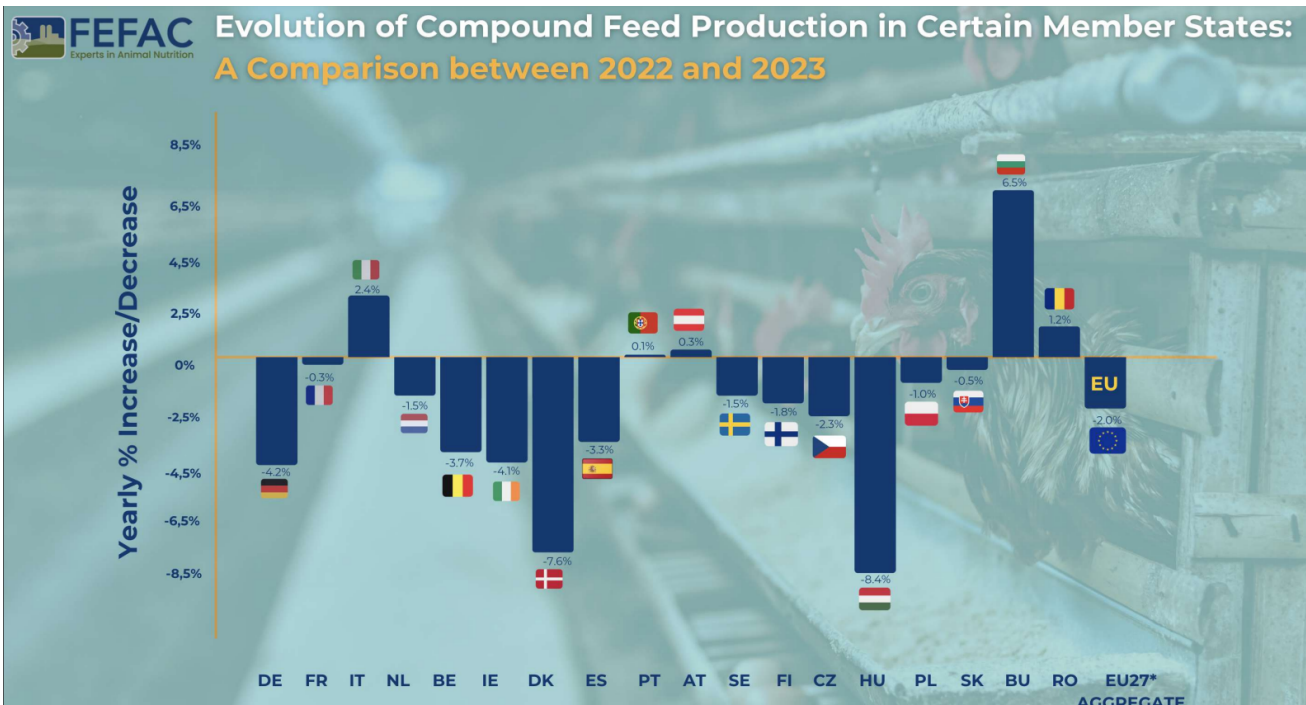
Organic acids are an excellent tool to compensate for the ban on ZnO

The article shows that organic acids have similar positive effects as zinc oxide. They act antimicrobial, modulate the immune system, maintain the gut morphology, fight pathogenic microbes, and also act – slightly – antioxidant. Additionally, they have a significant advantage: they are not harmful to the environment. Organic acids used in the proper pH range and combination are good tools for replacing zinc oxide.

References on request

FEFAC: Quick Overview of 2023 EU Compound Feed Production





Total Production 2023: 144.3 million metric tons for farmed animals

Change from 2022: 2% decrease

Factors Influencing Decrease

Political and Market Pressures: Addressing crises and the shift towards sustainable feed.

Climate and Diseases: Effects of droughts, floods, Avian Influenza (AI), and African Swine Fever (ASF) on raw material supply and animal production.

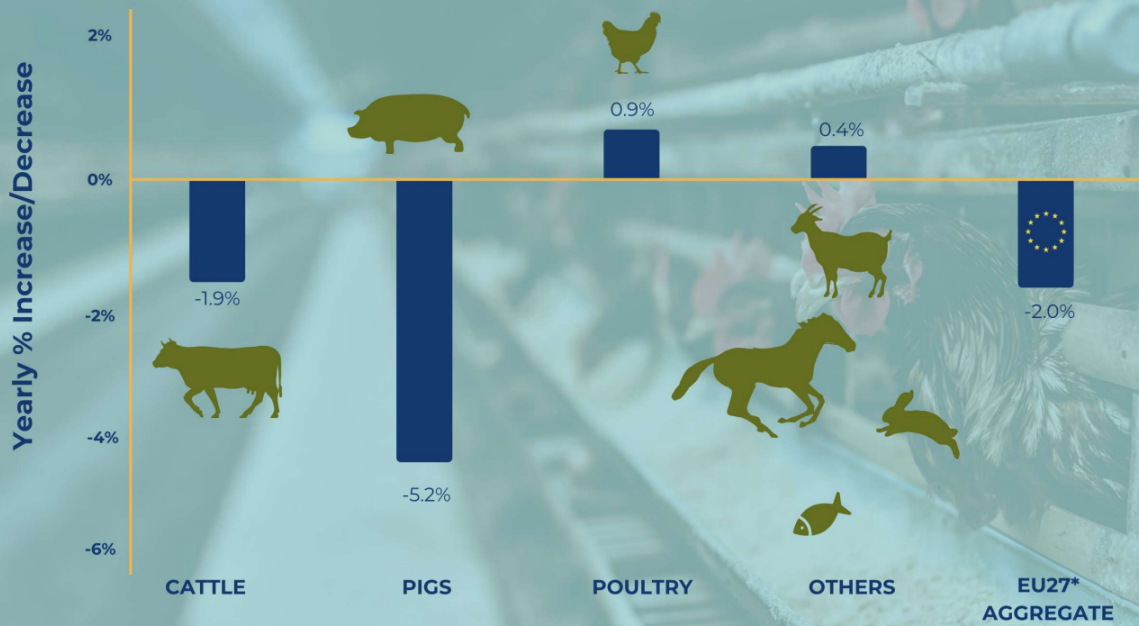
National Policies: Initiatives for greenhouse gas and nitrate emission reduction.

Consumer Trends: Food price inflation impacting demand.

Production Variability: Different trends across EU Member States, with notable decreases in countries like Germany, Ireland, Denmark, and Hungary, and slight increases in Austria, Bulgaria, Italy, and Romania.

Sector-Specific Trends

Evolution of Compound Feed Production per Category: A Comparison between 2022 and 2023



By Species

Pig Feed: Major decline of nearly 2.5 million tons. Key challenges included:

- Loss of export markets, particularly in Asia
- Negative media impact in Germany
- Significant production drop in Denmark (-13.6%) and Spain (loss of 800,000 metric tons)
- Italy's ongoing struggle with ASF

Poultry Feed: Increase by 0.9 million tons, yet still 700,000 metric tons below 2021 levels. Challenges included declines in Hungary and Czechia due to reduced broiler production.

Cattle Feed: Decrease of 0.8 million tons from 2022.

2024 key factors

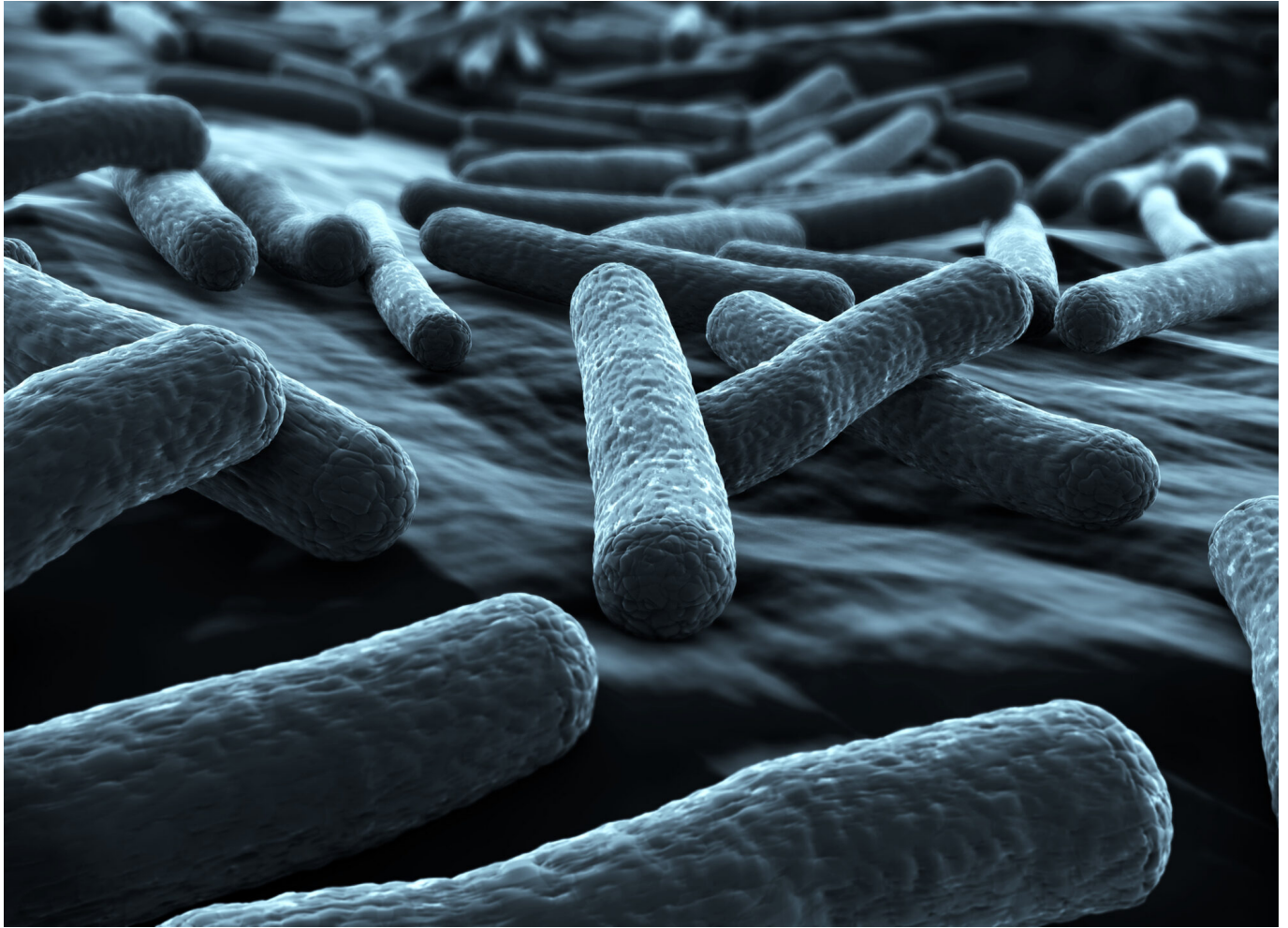
- Animal disease
- Economic instability, persistent food price inflation
- Weather irregularities
- Continued imports of poultry meat from Ukraine
- "Green and animal welfare" policies affecting local production

Summary

The EU's compound feed production in 2023 faced numerous challenges, leading to an overall decrease. The pig feed sector was most severely hit, while poultry feed showed some recovery. The influence of environmental, economic, and policy factors played a significant role in shaping these trends. Despite the price of feed cereals falling back to the levels seen before Russia's invasion of Ukraine, these challenges will continue to be felt in 2024.

Source: [FEFAC](#)

Endotoxins in 250 words



Dr Inge Heinzl, EW Nutrition

Endotoxins are... toxic, of course. The part “endo” in their name means that they are part of the bacterial cell, or, to specify it, they are part of the outer membrane of Gram-negative bacteria such as *E. coli*, *Salmonella*, *Shigella*, *Klebsiella*, and *Pseudomonas*.

When do they occur?

Always. Endotoxins are released with the lysis of bacteria, e.g., at the end of their life cycle, due to the effective immune defense of the host or treatments. The other possibility is bacterial growth as the membrane gets restructured and the endotoxins (or lipopolysaccharides -LPS-) are liberated.

What is the problem?

The “normal” occurrence (animals and humans always have Gram-negative bacteria in their gut) does not matter, because gut cells do not have receptors to recognize them as a danger in their apical side. However, when the barrier function is compromised, they pass into the bloodstream.

The liver still detoxifies small amounts. The problem comes with higher amounts of endotoxins in the bloodstream. Then, they provoke a strong immune reaction, feed intake drops, and nutritional resources are shifted from growth and production to immunity. These performance drops affect the profitability of the farmer.

What can be done?

Use broad-spectrum toxin binders that

- contain clay minerals showing high affinity and selectivity against endotoxins
 - contain yeast cell walls, which, in addition to their binding capacity, support the immune response through macrophage activation and are involved in modulating microflora and bacterial load from the intestine
 - provide adequate liver protection.
-

Meat quality is a result of genetics, feeding, the microbiome, and the handling of animals and meat



by **Dr. Inge Heinzl**, Editor EW Nutrition

Nowadays, nutrition is no longer about pure nutrient intake; enjoyment is also a priority. Consumers attach great importance to the high quality of food and, therefore, also of meat. The genetic selection for faster growth and feeding high-energy diets made meat production more efficient and shortened the raising period. However, this selection may sometimes also result in challenges to meat quality, such as worse water holding capacity, less marbling, less flavor, and reduced storage & processing properties.

The following article will provide detailed information about what meat quality is, how the gut microbiota influences it, and how we can increase meat quality by feeding and modulating the intestinal microflora.

Which factors can contribute to meat quality?

Meat quality is a complex term. On the one hand, meat quality covers measurable parameters such as the content of nutrients, moisture, microbial contamination, etc. On the other hand, and to no small extent, the consumers' preferences are significant. Since meat today is often sold as cuts or in parts (e.g., broiler drumsticks, breast), processing also affects the quality of meat and meat products.

Physical characteristics are objective determinants of meat quality

Physical characteristics are parameters that can be measured. For meat, the following measurable parameters determine meat quality:

1. Fat content and fatty acid composition influence tenderness and taste

Some years ago, the majority of consumers asked for completely lean meat, which, fortunately, has now changed. Fat is a flavor carrier. Especially intramuscular fat (marbling) melts during the preparation, making the meat tender, juicy, and taste good. Fat also transports fat-soluble vitamins.

A further criterion is the composition of the fat, the fatty acids. Geese fat, e.g., is known for its high content of oleic, linoleic, linolenic, and arachidonic acid, all of them derivatives of the enzymatic denaturation of stearic acid ([Okruszek, 2012](#)).

One exception is cholesterol. Although belonging to the lipids and improving the sensory quality of meat, consumers prefer meat with low cholesterol content.

2. Protein and amino acid content influence the meat value

The content and the composition of protein are important factors in meat quality. Protein is essential for constructing and maintaining organs and muscles and for the functionality of enzymes. The human body needs 20 different amino acids for these tasks, eleven of which it can manufacture by itself. Nine amino acids, however, must be provided by food and are called essential amino acids. Meat is a highly valuable protein source, rich in protein and essential amino acids. The protein quality, therefore, includes the chemical and amino acid score, the index for essential amino acids, and the biological value.

In addition to the pure nutritional value, amino acids contribute to flavor and taste. These flavor amino acids directly influence meat's freshness and flavor and include threonine, alanine, serine, lysine, proline, hydroxyproline, glutamic acid (glutamate is important for the umami taste), aspartic acid, and arginine.

3. Vitamins and trace elements are essential nutrients

Meat is a primary source of B vitamins (B1-B9) and, together with other animal products such as eggs and milk, the only provider of Vitamin B12. Vitamin A is available in the innards, vitamin D in the liver and fat fish, and vitamin K in the flesh.

The most important mineral compounds in meat are zinc, selenium, and iron. Humans can utilize the iron from animal sources particularly well.

4. pH and speed of pH decline decide if the meat is suited for cooking

Since broiler chicken meat nowadays is usually consumed as cut-up pieces or processed products, the appearance at the meat counter or in the plastic box is essential for being sold. The color, seen as an apparent measurement of the freshness and quality of the meat, is influenced by the pH. The muscle pH post-mortem plays an essential role in meat quality. Due to the glycolytic process, the pH post-mortem is a good indication for evaluating physiological meat quality. A rapid pH decline post-mortem to 5.8-6.0 in most cases leads to pale, soft, and exudative (PSE) meat with reduced water retention ([Džinić et al., 2015](#)), whereas a high ultimate pH results in dark, firm, and dry (DFD) meat with poor storage quality ([Allen et al., 1997](#))

5. Nobody wants meat like leather

The shear force is a measure of the tenderness of the meat. To determine the shear force, the meat undergoes the process of cooking and chilling. Afterward, standardized meat blocks, with fibers running along the length of the sample, are put into the Warner-Bratzler system. The blade used simulates teeth, and the system measures the force necessary to tear the piece of meat.

6. Microbial contamination is a no-go

The microbial contamination of the meat often occurs during the slaughter process. Let's take a look at salmonella or campylobacter in poultry. The chickens take up salmonella with contaminated feed or water. Campylobacter is transmitted by infected wild birds, inadequately cleaned and disinfected cages, or contaminated water. The bacteria proliferate in the intestine. At slaughter, the intestine's microorganisms can spread onto the meat intended for human consumption.

7. High water holding capacity is necessary to have tender meat

The moisture content contributes to the meat's juiciness and tenderness and improves its quality. If the meat loses its moisture, it gets tough, and quality decreases. Additionally, drip loss reduces the nutritional value of meat and its flavor.

8. Fat oxidation makes meat rancid, and oxidative stress can cause myopathies in broiler breasts

Rancidity of meat occurs when the fat in the flesh gets oxidized. There are different signs of meat rancidity: bad odor, changed color, and a sticky, slimy texture. Poultry meat is considered more susceptible to the development of oxidative rancidity than red meat. This can be explained by its higher content of phospholipids, PUFAs, especially in the thighs. The breast meat, however, has a relatively low level of intramuscular fat (up to 2 %) and, additionally, myoglobin is a natural antioxidant.

But oxidative stress in broiler breasts – and this more and more happens due to a selection of always bigger breasts – can lead to muscle myopathies such as white stripes or wooden breasts, making the meat only usable for processed products.

Sensory meat quality addresses the human senses

Besides physical quality, the sensory and chemical characteristics are essential to meat's economic importance. All attributes of meat that stimulate the human senses (vision, smell, taste, and touch) belong to the sensory quality. It, therefore, is more subjective and hard to determine. The most important features

for the consumer include color (attractive or unattractive), texture (tenderness, juiciness, marbling, drip loss), and taste/ flavor ([Thorslund et al., 2016](#)).

The appearance is the first impression

Nowadays, meat is often sold as cuts lying in polystyrene or clear plastic trays, over-wrapped with transparent plastic films, so the appearance is paramount. The meat must show an attractive color. Muscle myopathies, such as the ones occurring in chickens, would not meet consumers' needs.

How does the flavor of meat develop?

There is a reaction between reducing sugars and amino acids when meat is cooked ([Mottram, 1998](#)). This Maillard reaction, along with the degradation of vitamins, lipid oxidation, and their interaction, is responsible for the production of the volatile flavor components forming the characteristic aroma and flavor of cooked meat ([MacLeod, 1994](#)). [Werkhoff et al. \(1990\)](#) consider cysteine and methionine the most significant contributors to meat flavor development. One factor deteriorating this quality characteristic is lipid peroxidation, which turns the taste to rancid.

Some sensory characteristics are related to physical ones

The parameters of sensory meat quality can be partly explained by measurable parameters. Water retention, e.g., influences the juiciness of the meat. The palatability increases with higher intramuscular fat or marbling ([Stewart et al., 2021](#)), the initial pH and the speed of decline decide if the flesh will be pale, soft, and exudative or normal, and lipid peroxidation is the leading cause of a decrease in meat quality ([Pereira & Abreu, 2018](#)).

Processing quality

For the processing quality, muscle structure, chemical ingredient interactions, and muscle post-mortem changes are decisive ([Berri, 2000](#)).

Does the microbiome influence the meat quality?

The gastrointestinal tract of monogastric animals disposes of a microbiome of primarily bacteria, mainly anaerobic Gram-positive ones ([Richards et al., 2005](#)). With its complex microbial community, the digestive tract is responsible for digesting feed and absorbing nutrients, but also for eliminating pathogens and developing immunity. Gut microbiotas play an essential role in digestion, are decisive concerning the synthesis of fatty acids, proteins, and vitamins, and, therefore, influence meat quality ([Chen, 2022](#)).

Intestinal microbiotas vary by species/breeds and age ([Ma et al., 2022](#); [Sun et al., 2018](#)), and so does meat quality. For example, Duroc pigs with meat of high tenderness, good flavor, and excellent tastiness show different microbiota than other breeds ([Xiao, 2017](#)). [Zhao et al. \(2022\)](#) examined high- and low-fat Jinhua pigs, with the high-fat pigs showing more increased backfat thickness but also a higher fat content in the longissimus dorsi. They found low-fat pigs showed a higher abundance of *Prevotella* and *Bacteroides*, *Ruminococcus* sp. AF12-5, *Faecalibacterium* sp. OFO4-11AC und *Oscillibacter* sp. CAG:155, which are all involved in fiber fermentation and butyrate production. The high-fat animals showed a higher abundance of Firmicutes and Tenericutes, indicating that they are responsible for higher fat production of the organism in general but also a better fat disposition in the flesh. [Lei et al. \(2022\)](#) showed that abdominal fat was positively correlated with the occurrence of *Lachnospirillum* and Christensenellaceae.

The intestinal microbiota-muscle axis enables us to improve meat quality by controlling intestinal microbiota ([Lei, 2022](#)). However, to develop strategies to enhance the quality of meat, understanding the composition of the microbiota, the functions of the key bacteria, and the interaction between the host and microbiota is of utmost importance ([Chen et al., 2022](#)).

Different factors influence the microbiome

Apart from that microbiotas are different in different breeds, they are additionally influenced by diseases, feeding (diets, medical treatments with, e.g., antibiotics), and the environment (climate, geographical position). This could be shown by different trials. The genetic influence on microbiota was impressively documented by [Goodrich et al. \(2014\)](#), who detected that the microbiomes of monozygotic twins differ less than the ones of dizygotic twins. [Lei et al. \(2022\)](#) compared the microbiota of two broiler breeds (Arbor Acres and Beijing-You, the last one with a higher abdominal fat rate) and found remarkable differences in their microbiota composition. When raising them in the same environment and with the same feed, the microbiotas became similar. [Zhou et al. \(2016\)](#) contrasted the cecal microbiota of five Tibetan chickens from five different geographic regions with Lohmann egg-laying hens and Daheng broiler chickens. Besides seeing a difference between the breeds, slightly distinct microbiota between the regions could also be noticed.

The intestinal microbiome can actively be changed by

- promoting the wanted microbes by feeding the appropriate nutrients (e.g., prebiotics)
- reducing the harmful ones by fighting them, for example, with organic acids or phytomolecules
- directly applying probiotics and adding, therefore, desired microbes to the microbiome.

An increase in the abundance of *Lactobacillus* and *Succiniclasticum* could be achieved in pigs by feeding them a fermented diet, and *Mitsuokella* and *Erysipelotrichaceae* proliferated by adding a probiotic containing *B. subtilis* and *E. faecalis* to the diet ([Wang et al., 2022](#)).

How to change the intestinal microbiome to improve meat quality?

Before changing the microbiome, we must know which microbes are “responsible” for which characteristics. However, the microbiotas do not act individually but as consortia. The following table shows a selection of bacteria that, besides supporting the gut and its functions, influence meat quality in some way.

Metabolites	Producing bacteria	Biological functions and effects on pigs
Short-chain fatty acids (acetate, butyrate, and propionate)	Ruminococcaceae Ruminococcus Lachnospiraceae Blautia Roseburia Lactobacillaceae Clostridium Eubacterium Faecalibacterium Bifidobacterium Bacteroides	Regulate lipid metabolism Improve meat quality
Lactate	Lactic acid bacteria Bifidobacterium	Important metabolite for cross-feeding of SCFA-producing microbiota
Bile acids (primary and secondary bile acids)	Clostridium species Eubacterium Parabacteroides Lachnospiraceae	Regulate lipid metabolism

Ammonia	Amino acid fermenting commensals Helicobacter	By-product of amino acid fermentation Inhibits short-chain fatty acid oxidation
B Vitamins and vitamin K	Bacteroides Lactobacillus	Serve as coenzymes in neurological processes (B vitamins) • Essential vitamin for proper blood clotting (vitamin K)

Table 1: Bacteria influencing meat quality (according to [Vasquez et al., 2022](#))

Fat for meat quality is intramuscular fat

If we talk about increasing fat to improve meat quality, we talk about increasing intramuscular fat or marbling, not depot fat. The fat in meat-producing animals is mostly a combination of triglycerides from the diet and fatty acids synthesized. Fat deposition and composition in non-ruminants reflect the fatty acid composition of the diet but are also closely related to the design of the microbiome; short-chain fatty acids in monogastric, e.g., are exclusively produced by the gut microbiome ([Dinh et al., 2021](#); [Vasquez et al., 2022](#)). Intramuscular fat is mainly made of triglycerides but also disposes of phospholipids associated with proteins, such as lipoproteins or proteolipids, influencing meat flavor. The fermentation of indigestible polysaccharides or amino acids results in short-chain or branched-chain fatty acids, respectively. Lactate, produced by lactic acid bacteria, is utilized by SCFA-producing microbiota. An imbalance in the microbiome fosters lipid deposition, as shown by [Kallus and Brandt \(2012\)](#), who found a higher proportion of Firmicutes to Bacteroidetes (50% higher) in obese mice than in lean ones. In a trial described by [Zhou et al. \(2016\)](#), tiny Tibetan chickens with a low percentage of abdominal fat were compared to two breeds (Lohmann layers and Daheng broilers) being large and with a high percentage of abdominal fat. The Tibetan chickens showed a two to four-fold higher abundance of Christensenellaceae in the cecal microbiome. Christensenellas belong to the bacterial strain of firmicutes. They are linked to slimness in human nutrition, which was already proven by [Goodrich et al. \(2014\)](#) and is the contrary stated by [Lei et al. \(2022\)](#).

Another example was provided by [Wen et al. \(2023\)](#). They compared two broiler enterotypes distinguished by Clostridia vadinB60 and Rikenellaceae_RC9_gut and saw that the type with an abundance of Clostridia_vadinBB60 showed higher intramuscular fat content but also more subcutaneous fat tissue. The scientists also found another bacterium especially responsible for intramuscular fat: A lower plethora of Clostridia vadinBE97 resulted in a higher intramuscular fat content in breast and thigh muscles but not adipose tissues. Similar results were achieved in a trial with pigs and mice: Jinhua pigs showed a significantly higher level of intramuscular fat than Landrace pigs. When transplanting the fecal microbiota of the two breeds in mice, the mice showed similar characteristics in fat metabolism as their donors of feces ([Wu et al., 2021](#)).

According to several studies (e.g., [Chen et al., 2008](#); [Liu et al., 2019](#)), intramuscular fat in chicken has a low heritability but may be controlled by feeding up to a certain extent. In pigs, [Lo et al. \(1992\)](#) and [Ding et al. \(2019\)](#) found a moderate to low (0.16 – 0.23) heritability for intramuscular fat, but [Cabling et al. \(2015\)](#) calculated a heritability of 0.79 for the marbling score.

At least, especially the composition of fatty acids can easily be changed in monogastric ([Aaslyng and Meinert, 2017](#)). [Zou et al. \(2017\)](#) examined the effect of Lactobacillus brevis and tea polyphenol, each alone or combining both. Lactobacillus is probably involved in turning complex carbohydrates into metabolites lactose and ethanol, but also acetic acid and SCFA. SCFAs are mainly produced by Saccharolytic and anaerobic microbiota, aiding in the degradation of carbohydrates the host cannot digest (e.g., cellulose or resistant polysaccharides into monomeric and dimeric sugars and fermenting them subsequently into short-chain fatty acids). Including fibers and various oligosaccharides was shown to increase the gut microbiome's fermentation capacity for producing short-chain fatty acids.

In a trial conducted by [Jiao et al. \(2020\)](#), they showed that SCFAs applied in the ileum modulate lipid metabolism and lead to higher meat quality in growing pigs. A plant polyphenol was used by [Yu et al. \(2021\)](#). The added resveratrol, a plant polyphenol in grapes and grape products, to the diet of Peking ducks and could significantly increase intramuscular fat.

Oxidation of lipids and proteins must be prevented

The composition of the fatty acids and occurring oxidative stress in adipose and muscle tissue influences or impacts meat quality in farm animals ([Chen et al., 2022](#)). During the last few years, the demand for healthier animal products containing higher levels of polyunsaturated fatty acids has increased. Consequently, the risk of lipoperoxidation has risen ([Serra et al., 2021](#)). Solutions are needed to counteract this deterioration of meat quality. As can be seen in table 1, ammonia produced by amino acid-fermenting commensals and *Helicobacter* inhibits the oxidation of SCFAs. [Ma et al. \(2022\)](#) changed the microbiome of sows by feeding a probiotic from mating till day 21 of lactation and achieved a decreased level of MDA, a sign of reduced oxidative stress. Similar results were achieved by [He et al. \(2022\)](#). In their trial, the supplementation of 200 mg yeast β -glucan/kg of feed significantly decreased the abundance of the phylum WPS-2 as well as markedly increased catalase, superoxide dismutase (both $p < 0.05$) and the total antioxidant activity ($p < 0.01$) in skeletal muscle. Another approach was done by [Wu et al. \(2020\)](#) in broilers. They applied glucose oxidases (GOD) produced by *Aspergillus niger* and *Penicillium amagasakiense*. Both enzymes did not disturb but improved beneficial bacteria and microbiota. The GOD produced by *A. niger* reduced the content of malondialdehyde in the plasma.

Another alternative is antioxidant extracts from plants ([Džinić, 2015](#)). As consumers nowadays bet more on natural products, they would be good candidates. They are considered safe and, therefore, well-accepted by consumers and have beneficial effects on animal health, welfare, and production performance.

[Hazrati et al. \(2020\)](#) showed in a trial that the essential oils of ajwain and dill decreased the concentration of malondialdehyde (MDA) in quails' breast meat and, therefore, lipid peroxidation and reduced cooking loss. The antioxidant effects of thymol and carvacrol were shown by [Luna et al. \(2010\)](#). The group receiving the essential oils showed lower TBARS in the thigh samples than the control group but similar TBARS to the butylated hydroxytoluene-provided group.

Protein quality is a question of essential amino acids

Protein with a high content of essential amino acids is one of the most critical components of meat. [Alfaig et al. \(2014\)](#) tested probiotics and thyme essential oil in broilers. They found out that the content of EAAs in breast and thigh muscles numerically increased gradually from the control over the probiotic and a combination of a probiotic up to the thyme essential oil group. A significant ($p < 0.05$) increase in all tested amino acids (arginine, cysteine, phenylalanine, histidine, isoleucine, leucine, lysine, methionine, threonine, and valine) could be observed in the samples of the breast and the thigh muscles when comparing the thyme essential oil group with the control. [Zou et al. \(2017\)](#) provided similar results, showing a significant increase in leucine and glutamic acid as well as a numerical increase in lysin, valine, methionine, isoleucine, phenylalanine, threonine, asparagine, alanine, glycine, serine, and proline through the addition of a combination of *Lactobacillus brevis* and tea polyphenols. They also determined an increase in the beneficial bacteria *Lactobacillus* and *Bacteroides*. The experimental results led them to the assumption that both additives may also improve the taste of meat by increasing some of the essential and delicate flavors produced by amino acids.

Tenderness is closely related to drip loss

The already mentioned trial conducted by [Lei et al. \(2022\)](#) with two different broiler breeds (Arbor Acres and Beijing-You) having different microbiota showed a negative correlation between drip loss and the abundance of *Lachnospirillum*. They remodeled the Arbor Acres' microbiome by applying a bacterial suspension derived from the Beijing-You breed and decreased drip loss in their meat. [He et al. \(2022\)](#) changed the microbiome by adding yeast β -glucan to the diet of finisher pigs. They achieved a reduced cooking loss (linear, $p < 0.05$) and a lower drip loss ($p < 0.05$), together indicating a better water-holding capacity, as well as a decreased lactate content. The addition of a multi-species probiotic to the diet of finishing pigs tended to result in lower cooking and drip loss ($p < 0.1$) besides modulating the intestinal flora

(higher lactobacilli and lower *E. coli* counts in the feces) ([Balasubramanian et al., 2017](#)) and the inclusion of *Lactobacillus brevis* and tea polyphenol individually or in a synergistic combination improved water holding capacity and decreased drip loss ([Zou et al. \(2017\)](#)).

[Puvača et al. \(2019\)](#) observed the lowest drip-loss values in breast meat and thigh with drumstick through feeding chickens 0.5 g or 1.0 g of hot red pepper per 100 g of feed, respectively, in the grower and finisher phase. The feeding of resveratrol reduced drip loss of Peking ducks' leg muscles. SCFA infused into the ileum enlarged the longissimus dorsi area and alleviated drip loss ([Jiao et al, 2021](#)).

The decrease and increase of the pH after slaughtering determines meat quality

The pH in the muscles of a living animal is about 7.2. With slaughtering and bleeding, the energy supply of the muscles is interrupted. The stored glycogen gets degraded to lactic acid, lowering the pH. Usually, the lowest pH value of 5.4-5.7 in meat is reached after 18 to 24 hours. Afterward, it starts to rise again.

In stressed animals, the stress hormones adrenalin and noradrenalin provoke a rushly occurring and, due to a lack of oxygen, anaerobic metabolism and the quick production of lactic acid. This too rapid decrease in pH leads to the denaturation of proteins in the muscle cells and reduced water-holding capacity. The result is PSE (pale, soft, and exudative) meat.

On the contrary, DFD meat (dark, firm, and dry) occurs if the glycogen reserves, due to challenges, are already used up, and the lactic acid production is insufficient. Especially PSE meat is closely related to breeds – some are more susceptible to stress, others less. However, some trials show that influencing pH in meat is possible to a certain extent.

[He et al., 2022](#) added yeast β -glucan to the diets of finishing pigs and a higher pH_{45 min} (linear and quadratic, $p < 0.01$) and a higher redness (a^* ; linear, $p < 0.05$) of the meat. [Wu et al. \(2020\)](#) achieved a significantly increased pH_{24h} through the addition of Glucose oxidase produced by *Aspergillus niger*.

Sensory characteristics are very subjective

In general, the sensory characteristics of meat are seen very individually. Some prefer lean, others fatty meat, some like meat with a characteristic taste, and others with a neutral. However, the typical meat taste of umami is partly determined by the nucleotide inosine monophosphate (IMP), which is regarded as an essential index for evaluating meat flavor and the acceptability of meat products. IMP provides about 40-fold higher umami taste than sodium glutamate ([Huang et al. 2022](#)). IMP is the organophosphate of inosin. Inosine, however, according to [Kroemer and Zitvogel \(2020\)](#), is produced by *Bifidobacterium pseudolongum*, which possibly can be controlled by feeding. Sun et al. (2018) compared Caoke and Partridge Shank chickens and divided them into free-range and cage groups. They found out that, except for acids, the amounts of flavor components were higher in the free-range than in the cage groups. The two housing systems also modified the microbiota, and Sun et al. took it as an indication that meat flavor, as well as the composition and diversity of gut microbiota, are closely associated with the housing systems. [Fu et al. \(2023\)](#) examined the addition of a mixture containing Pulsatilla, Gentian, and Rhizoma coptidis and a mixture with *Codonopsis pilosula*, *Atractylodes*, *Poria cocos*, and Licorice to the feed of Hungarian white geese. They saw that in both groups, the total amino acid levels, especially Glu, Lys, and Asp, increased, with, according to Liu et al. (2018), Glu and Asp directly affecting meat's freshness and flavor. [Yu et al. \(2021\)](#) achieved similar results by adding resveratrol to the diet of Peking ducks. The addition of the herbs additionally led to a higher Firmicutes/Bacteroidetes ratio and an increased level of lactobacilli ([Fu et al., 2023](#)).

How can EW Nutrition's feed additives

help to improve meat quality?

Meat quality is influenced by the microbiome. So, feed additives that stabilize the microbiome or promote certain beneficial bacterial strains are an opportunity.

Ventar D modulates the microbiome

Ventar D balances the microbiome by promoting beneficial bacteria such as lactobacilli and fighting harmful ones such as Clostridia, E. coli, and Salmonella. ([Heinzl, 2022](#)). In another trial with broilers, the addition of Ventar D to all feeds (100 g/t) showed an increase in short-chain fatty acids in the intestine:

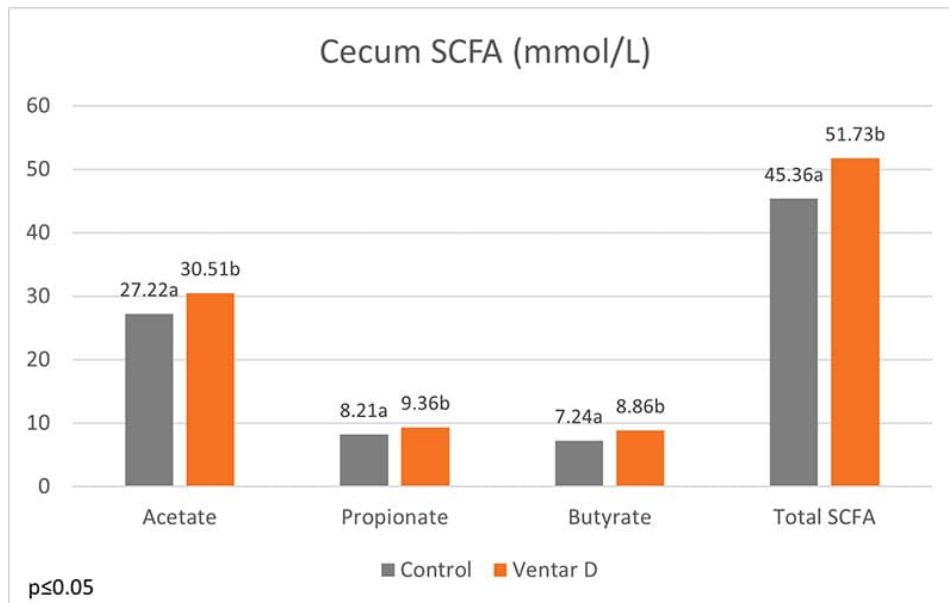


Figure 1: Short-chain fatty acids in the cecum of broilers

Santoquin countersteers oxidation

Another helpful product category is antioxidants. They can prevent the oxidation of lipids and proteins. For this purpose, EW Nutrition offers Santoquin M6*, a product tested by Kuttapan et al. (2021). Santoquin M6 was tested concerning its ability to minimize the oxidative damage caused by feeding oxidized fat. A control group receiving oxidized fat in feed was compared to one receiving oxidized fat plus 188 ppm Santoquin M6 ($\pm$ 125 ppm ethoxyquin). The main parameters for this study were TBARS in the breast muscle, the incidence of wooden breast, and the live weight on day 48.

Results indicated that the inclusion of Santoquin M6 reduced the production of TBARS in the breast muscles, demonstrating a lower level of oxidative stress in the breast muscles.

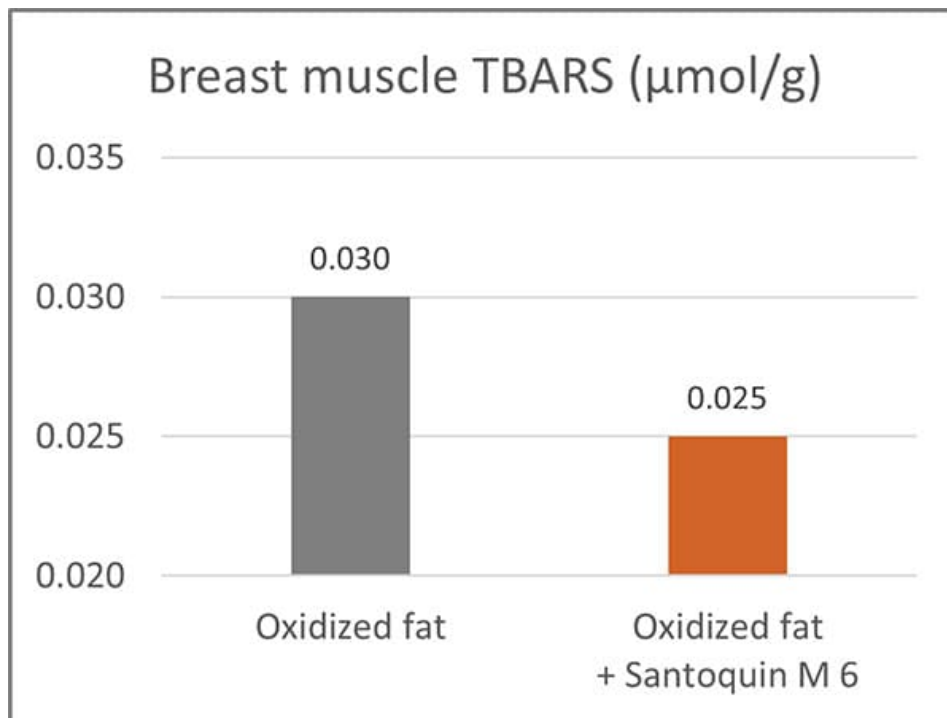


Figure 2: Thiobarbituric acid reactive substances (TBARS) in broiler breast muscles. TBARS are formed as a by-product of lipid peroxidation.

Additionally, it reduced the incidence of severe woody breasts (Score 3) by almost half and helped mitigate the impact of breast muscle degradation due to increased oxidative stress.

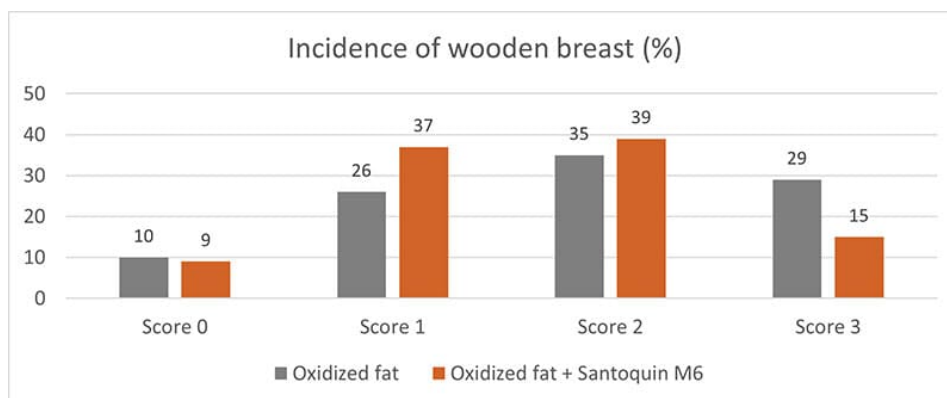


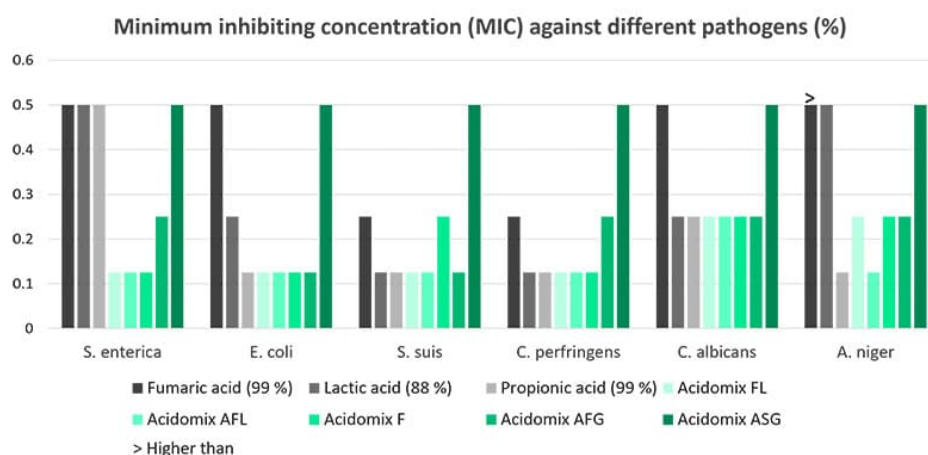
Figure 3: Incidence of wooden breast in broilers

*Usage of ethoxyquin is dependent on country regulations.

Feed hygiene with Acidomix products minimizes harmful pathogens

The Acidomix product line offers liquid, powdery, and micro-granulated products to be added to feed and water. The organic acids in Acidomix directly act against pathogens in the feed and the water and help keep the intestinal flora in balance.

A trial evaluating the effect of different Acidomix products against diverse pathogens showed lower MICs for most Acidomix products than for single organic acids. The trial was conducted with decreasing concentrations of the Acidomix products (2 – 0.015625 %) and 10^5 CFU of the respective microorganisms (microtiter plates; 50 μl bacterial solution and 50 μl diluted product).



Feeding is the one side, slaughtering the other one

With feeding, the microbiota and some meat characteristics can be changed; however, the last step, handling the animals before and the meat after slaughtering also significantly contributes to a good quality of meat. Stress due to the transport and the slaughterhouse atmosphere, combined with stress-sensible breeds, can lead to PSE meat. Incorrect handling at the slaughterhouse can lead to meat contaminated with pathogens.

Combining feeding measures with professional and calm handling of the animals is the best strategy to achieve high-quality meat.

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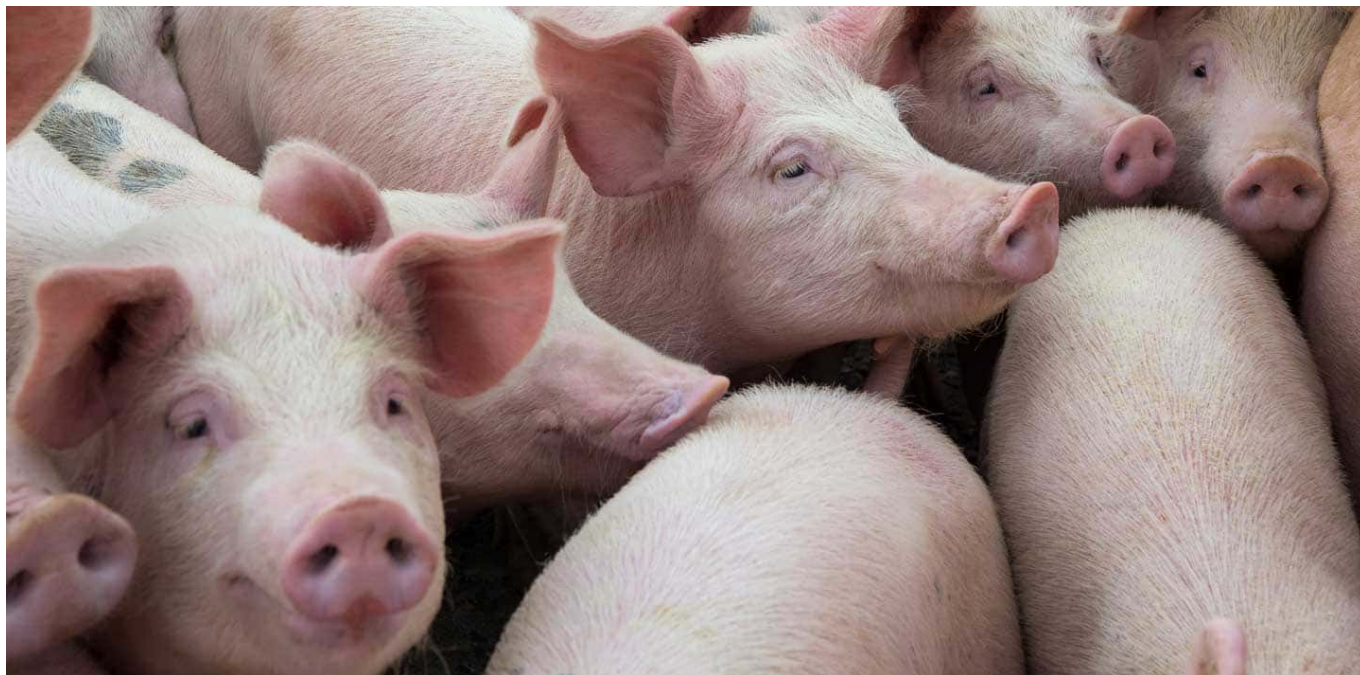
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Salmonella in pigs: a threat for humans and a challenge for pig producers



By **Dr. Inge Heinzl**, Editor, EW Nutrition

Salmonellosis is third among foodborne diseases leading to death ([Ferrari, 2019](#)). More than 91,000 human cases of Salmonellosis are reported by the EU each year, generating overall costs of up to €3 billion a year ([EFSA, 2023](#)), 10-20% of which are attributed to pork consumption ([Soumet, 2022](#)). The annual costs arising from the resulting human health losses in 2010 were about €90 million ([FCC Consortium, 2010](#)). Take the example of Ireland, where a high prevalence of Salmonella in lymph nodes still shows a severe issue pre-slaughter and a big challenge for slaughterhouses to stick to the process hygiene requirements ([Deane, 2022](#)).

Several governments already have monitoring programs in place, and the farms are categorized according to the salmonella contamination of their pigs. In some countries, e.g., Denmark, an economic penalty of 2% of the carcass value must be paid if the farm has level 2 (intermediate seroprevalence) and 4-8% if the level is 3. Other countries, e.g., Germany, the UK, Ireland, or the Netherlands, use quality assurance schemes. The farmers can only sell their carcasses under this label if their farm has a certain level.

Let's take a quick look at the genus of Salmonella

Salmonellas are rod-shaped gram-negative bacteria of the family of enterobacteria that use flagella for their movement. They were named after the American vet Daniel Elmer Salmon. The genus of Salmonella consists of two species (*S. bongori* and *S. enterica* with seven subspecies) with in total more than 2500 serovars (see Figure 1). The effects of the different serovars can range from asymptomatic carriage to severe invasive systemic disease ([Gal-Mor, 2014](#)). All Salmonella serovars generally can cause disease in humans; the rosa-marked ones already showed infections.

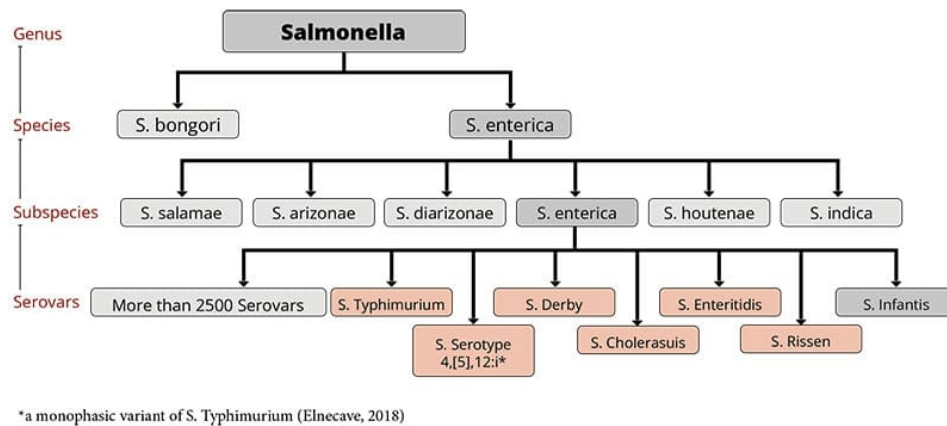


Figure 1: the genus of *Salmonella* with *Salmonella* serovars relevant for pigs (according to Bonardi, 2017: *Salmonella* in the pork production chain and its impact on human health in the European Union)

Within the group of *Salmonella*, some serovars can only reside in one or few species, e.g., *S. enterica* spp. *enterica* Serovar Dublin (*S. Dublin*) in bovines (Waldron, 2018) or *S. Cholerasuis* in pigs (Chiu, 2004). An infection in humans with these pathogens is often invasive and life-threatening (WHO, 2018). On the contrary, serovars like *S. Typhimurium* and *S. Enteritidis* are not host-specific and can cause disease in various species.

The serotypes *S. Typhi* and *S. Paratyphi* A, B, or C are highly adapted to humans and only for them pathogenic; they are responsible for the occurrence of typhus.

Serovars occurring in pigs and relevant for humans are, for example, *S. Typhimurium* (Hendriksen, 2004), *S. Serotype 4,[5],12:i* (Hauser et al., 2010), *S. Cholerasuis* (Chiu, 2004), *S. Derby* (Gonzalez-Santamarina, 2021), *S. Agona* (Brenner Michael, 2006) and *S. Rissen* (Elbediwi, 2021).

Transmission of *Salmonella* mostly happens via contaminated food

The way of transmission to humans depends on the serovar:

Human-specific and, therefore, only in humans and higher primates residing serovars *S. Typhi* and *Paratyphi* A, B, or C (typhoidal) are excreted via feces or urine. Therefore, any food or water contaminated with the feces or urine of infected people can transmit this disease (Government of South Australia, 2023). Typhoid and paratyphoid *Salmonellosis* occur endemic in developing countries with the lack of clean water and, therefore, inadequate hygiene (Gal-Mor, 2014).

Serovars which can cause disease in humans **and** animals (non-typhoidal), can be transmitted by

- animal products such as milk, eggs, meat
- contact with infected persons/animals (pigs, cows, pets, reptiles...) or
- other feces- or urine-contaminated products such as sprouts, vegetables, fruits....

Farm animals take salmonellas from their fellows, contaminated feed or water, rodents, or pests.

Symptoms of *Salmonellosis* can be severe

In the case of typhoid or paratyphoid *Salmonellosis*, the onset of illness is gradual. People can suffer from sustained high fever, unwellness, severe headache, and decreased appetite, but also from an enlarged spleen irritating the abdomen and dry cough.

A study conducted in Thailand with children suffering from enteric fever caused by the typhoid serovars *S. Typhi* and *Paratyphi* showed a sudden onset of fever and gastrointestinal issues (diarrhea), rose spots, bronchitis, and pneumonia (Thisyakorn et al., 1987)

The non-typhoid Salmonellosis is typically characterized by an acute onset of fever, nausea, abdominal pain with diarrhea, and sometimes vomiting ([WHO, 2018](#)). However, 5% of the persons – children with underlying conditions, e.g., babies, or people who have AIDS, malignancies, inflammatory bowel disease, gastrointestinal illness caused by non-typhoid serovars, and hemolytic anemia, or receiving an immunosuppressive therapy can be susceptible to bacteremia. Additionally, serovars like *S. Cholerasuis* or *S. Dublin* are apt to develop bacteremia by entering the bloodstream with little or no involvement of the gut ([Chiu, 1999](#)). In these cases, consequences can be septic arthritis, pneumonia, peritonitis, cutaneous abscess, mycotic aneurysm, and sometimes death ([Chen et al., 2007](#); [Chiu, 2004](#), [Wang et al., 1996](#)).

In pigs, *S. Cholerasuis* causes high fever, purple discolorations of the skin, and thereafter diarrhea. The mortality rate in pigs suffering from this type of Salmonellosis is high. Barrows orally challenged with *S. Typhimurium* showed elevated rectal temperature by 12h, remaining elevated until the end of the study. Feed intake decreased with a peak at 48h after the challenge and remained up to 120h after the challenge. Daily gain reduced during the following two weeks after infection. A higher plasma cortisol level and a lower IGF-I level could also be noticed. All these effects indicate significant changes in the endocrine stress and the somatotrophic axis, also without significant alterations in the systemic pro-inflammatory mediators ([Balaji et al., 2000](#))

To protect humans, Salmonella in pork must be restraint

There are three main steps to keep the contamination of pork as low as possible:

1. Keeping Salmonella out of the pig farm
2. Minimizing spreading if Salmonella is already on the farm
3. Minimizing contamination in the slaughterhouse

1. How to keep Salmonella out of the pig farm?

To answer this question, we must look at how the pathogen can be transported to the farm. According to the Code of Practice for the Prevention and Control of Salmonella on Pig Farms (Ministry of Agriculture, Fisheries and Food and the Scottish Executive Rural Affairs Department), there are several possibilities to infiltrate the pathogen into the farm:

- Diseased pigs or pigs which are ill but don't show any symptoms
- Feeding stuff or bedding contaminated with dung
- Pets, rodents, wild birds, or animals
- Farm personnel or visitors
- Equipment or vehicles

Caution with purchased animals!

To minimize/prevent the entry of Salmonella into the livestock, bought-in animals must come from reputable breeding farms with a salmonella monitoring system in place. As possible carrier animals are more likely to excrete Salmonella when stressed; they should be kept in isolation after purchasing. Additionally, the animals must go through a disinfectant foot bath before entering the farm.

Keep rodents, wild animals, and vermin in check!

Generally, the production site must be kept clean and as unattractive as possible for all these animals. Rests of feed must be removed, and dead animals and afterbirths must be promptly and carefully disposed of. A well-planned baiting and trapping policy should be in place to effectively control rodents.

Only selected people should enter the hog houses

In any case, the number of persons entering the hog house must be kept as low as possible. Farmworkers should be trained in the principles of hygiene. They should wear adequate clothing (waterproof boots and protective overalls) that can be easily cleaned/laundered and disinfected. The clothes/shoes should always be used only at this site. Thorough hand washing and the disinfection of the boots when entering and leaving the pig unit are a must.

If visits are necessary, the visitors should take the same measures as the farm workers. And, of course, they should not have had contact with another pig farm during the last 48 hours.

Keep pens, farm equipment, and vehicles clean!

Farm equipment should not be shared with other farms. If this cannot be avoided, it must be cleaned and disinfected before re-entering the farm. Also, the vehicles for the transport of the animals must be cleaned and disinfected as soon as possible after usage, as contaminated transporters always pose the risk of infection.

Feed should be Salmonella-free!

To get high feed quality, the feed should be purchased from feed mills/sources with a well-functioning bacterial control to guarantee the absence of Salmonella. It is essential that birds, domestic and wild animals cannot enter the feed stores.

It is also advised to keep dry feed dry as possibly contaminating Salmonella can multiply in such humid conditions. Additionally, all feed bins and delivery pipes for dry and wet feed must be consciously cleaned, and the damp feed pipes also disinfected.

The change from pellets to mash could be helpful as the pellets facilitate Salmonella colonization by stimulating the secretion of mucins ([Hedemann et al., 2005](#)).

For sanitation of the feed, we offer organic acids ([Acidomix product range](#)) or mixtures of organic acids and formaldehyde in countries where formaldehyde products are allowed ([Formycine](#)) to decrease the pathogenic load of the feed materials. In vitro trials show the effectiveness of the products:

For the in vitro trial with Formycine, autoclaved feed samples were inoculated with Salmonella enteritidis serovar Typhimurium DSM 19587 strain to reach a Salmonella contamination of 10^6 CFU/g of feed. After incubating at room temperature for three hours, Formycine Liquido was added to the contaminated feed samples at 0, 500, 1000, and 2000 ppm. The control and inoculated feed samples were further incubated at room temperature, and Salmonella counts (CFU/g) were carried out at 24, 48, 72 hours and on day 15. The limit of Salmonella detection was set at 100 CFU/g (10^2). Results are shown in figure 2.

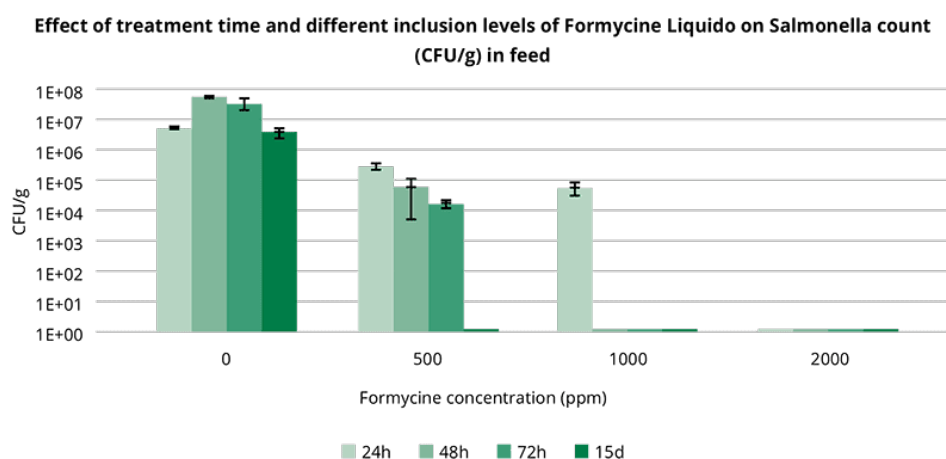


Fig. 2: Effect of treatment time and different inclusion levels of Formycine Liquido on the Salmonella count in feed

As important as uncontaminated feed is clean water for drinking. It can be achieved by taking the water from a main or a bacteriologically controlled water borehole. Regular cleaning/disinfection of the tanks, pipes, and drinkers is essential.

Bedding should be Salmonella-free

Straw material containing feces of other animals (rodents, pets) always carries the risk of Salmonella contamination. Also, wet or moldy bedding is not recommended because it is an additional challenge for the animal. To optimize the quality of bedding, the straw should be bought from reliable and as few as possible sources. The material must be stored dry and as far as practicable from the pig buildings ([Ministry of Agriculture, Fisheries and Food & Scottish Executive Rural Affairs Department, 2000](#)).

Vaccination is a beneficial measure

For the control of Salmonella in swine herds, vaccination is an effective tool. [De Ridder et al. \(2013\)](#) showed that an attenuated vaccine reduced the transmission of Salmonella Typhimurium in pigs. The vaccination with an attenuated S. Typhimurium strain, followed by a booster vaccination with inactivated S. Cholerasuis, showed better effects than an inactivated S. Cholerasuis vaccine alone ([Alborali et al., 2017](#)). [Bearson et al. \(2017\)](#) could delimitate transmission through less shedding and protect the animals against systemic disease.

To achieve the best effects, the producer must understand the diversity of Salmonella serovars to choose the most promising vaccination strategy ([FSIS, 2023](#)).

2. How to minimize the spreading of Salmonella on the farm?

If there are already cases of Salmonella on the farm, infected animals must be separated from the rest of the herd. Small batch sizes are beneficial, as well as not mixing different litters after weaning. If feasible, separate units for different production phases with an all-in/all-out system could break the reinfection cycle and help reduce Salmonella contamination on the farm. And also in this case, vaccination is helpful.

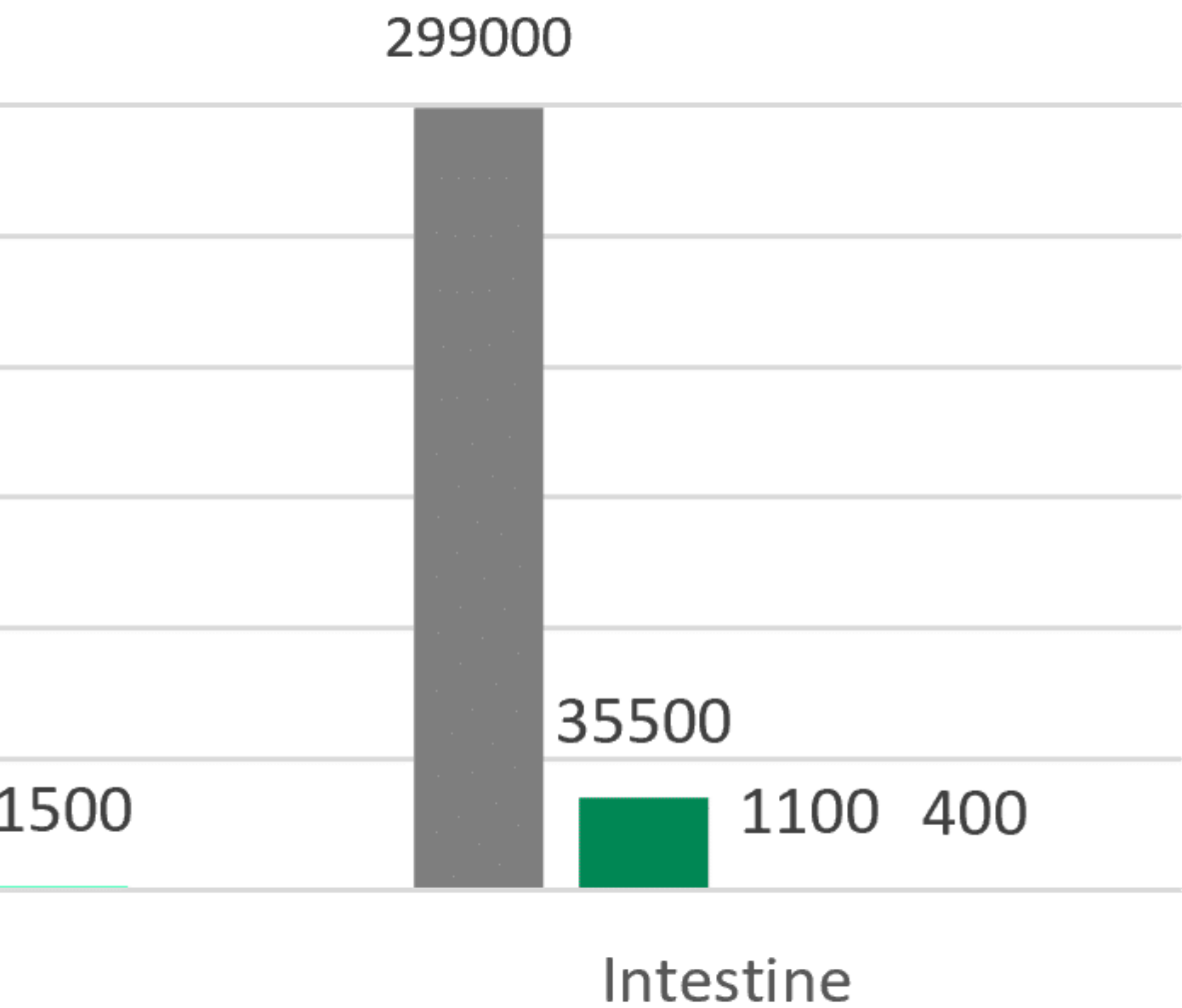
Salmonella doesn't like acid conditions

An effective tool is acidifying the feed with organic acids, as Salmonella doesn't like acid conditions. A trial was conducted with Acidomix AFG and Acidomix AFL to show their effects against Salmonella. For the test, 10^5 CFU/g of Salmonella enterica ser. Typhimurium was added to feed containing 1000 ppm, 2000 ppm, and 3000 ppm of Acidomix AFG or AFL. The stomach and intestine were simulated in vitro by adjusting the pH with HCl and NaHCO₃ as follows:

Stomach	2.8
Intestine	6.8-7.0

After the respective incubation, the microorganisms were recovered from feed and plated on an appropriate medium for CFU counting. The results are shown in figures 3 and 4.

lomis AFL



0 ppm

2000 ppm

3000 ppm

Phytomolecules can support pigs against *Salmonella*

Plant compounds or phytomolecules can also be used against *Salmonella* in pigs. Some examples of phytomolecules to be used are Piperine, Allicin, Eugenol, and Carvacrol. Eugenol, e.g., increases the permeability of the *Salmonella* membrane, disrupts the cytoplasmic membrane, and inhibits the production of bacterial virulence factors (Keita et al., 2022; Mak et al., 2019). Thymol and Carvacrol interact with the cell membrane by H bonding, also resulting in a higher permeability.

[An already published in vitro](#) trial conducted with our product [Ventar](#) D also showed excellent effects against *Salmonella* while sparing the beneficial gut flora. A further trial once more demonstrated the susceptibility of *Salmonella* to Ventar D. It showed that Ventar D controls *Salmonella* by suppressing their motility and, at higher concentrations, inactivating the cells (see figures 5 + 6):

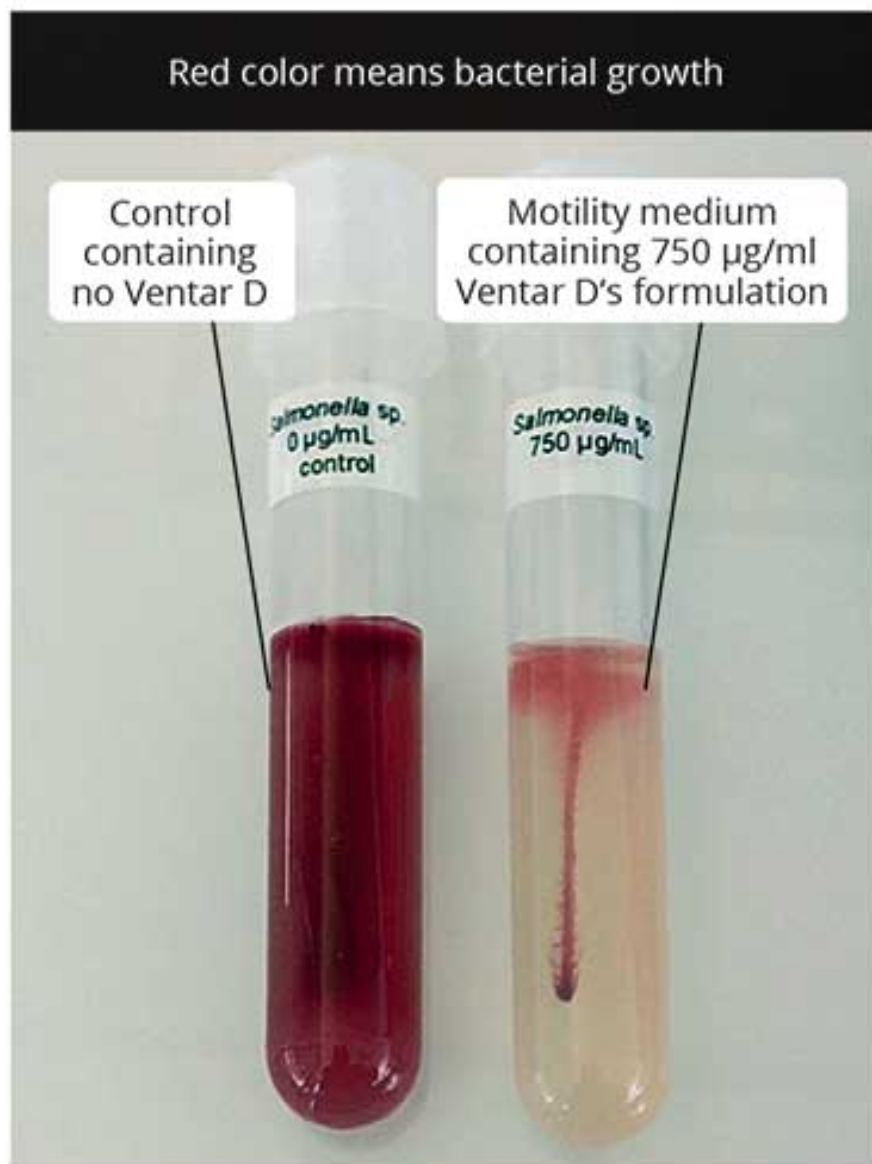


Figure 5: *S. enterica* motility test: on the left side – control; on the right side – motility medium containing 750 µg/mL of Ventar

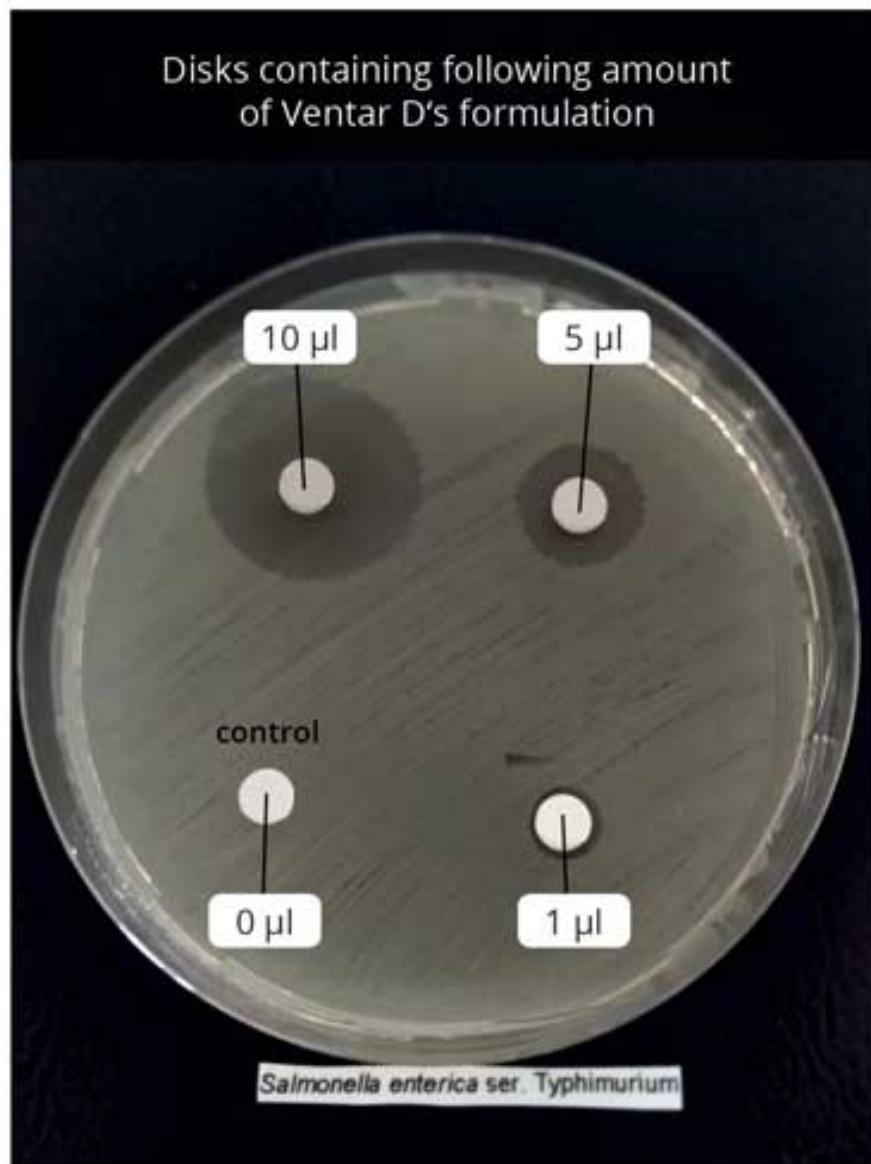


Fig 6 . Disk diffusion assay employing *S. enterica*. upper left side – disk containing 10 µL of Ventar; upper right – 5 µL; lower left – control; lower right – 1 µL.

In addition to the direct *Salmonella*-reducing effect, essential oils / secondary plant compounds / phytomolecules improve digestive enzyme activity and digestion, leading to increased nutrient absorption and better feed conversion ([Windisch et al., 2008](#)).

3. How can the farmer keep *Salmonella* contamination low in the slaughterhouse?

In general, the slaughterhouse personnel is responsible for adequate hygiene management to prevent contamination of carcasses and meat. However, also the farmer can make his contribution to maintain the risk of contamination in the slaughterhouse as low as possible. A study by [Vieira-Pinto \(2006\)](#) revealed that one *Salmonella*-positive pig can contaminate several other carcasses.

According to a trial conducted by [Hurd et al. \(2002\)](#), infection and, therefore, “contamination” of other pigs can rapidly occur, meaning that cross-contamination is a topic during transport to the slaughterhouse and in the lairages when the pigs come together with animals from other farms. The stress to which the pigs are exposed influences physiological and biochemical processes. The microbiome and animal's immunity are affected, leading to higher excretion of *Salmonella* during transport and in the lairages. So, the animals should not be stressed during loading and unloading or transportation. The trailer poses a further risk of

infection if it was not cleaned and disinfected before. So, reliable people who treat the animals well and keep their trailers clean should be chosen for transportation.

Pig producers are obliged to keep Salmonella in check – phytomolecules can help

At least in the EU, pig producers have the big duty to keep Salmonella low in their herds; otherwise, they will have financial losses. They are not only responsible for their farm, but also the slaughterhouses count on them. Besides the standard strict hygiene management and vaccination, farmers can use products provided by the industry to sanitize feed but also to support their animals directly with phytomolecules acting against pathogens and supporting gut health.

All these measures together should be a solution to the immense challenge of Salmonella, to protect people and prevent economic losses.

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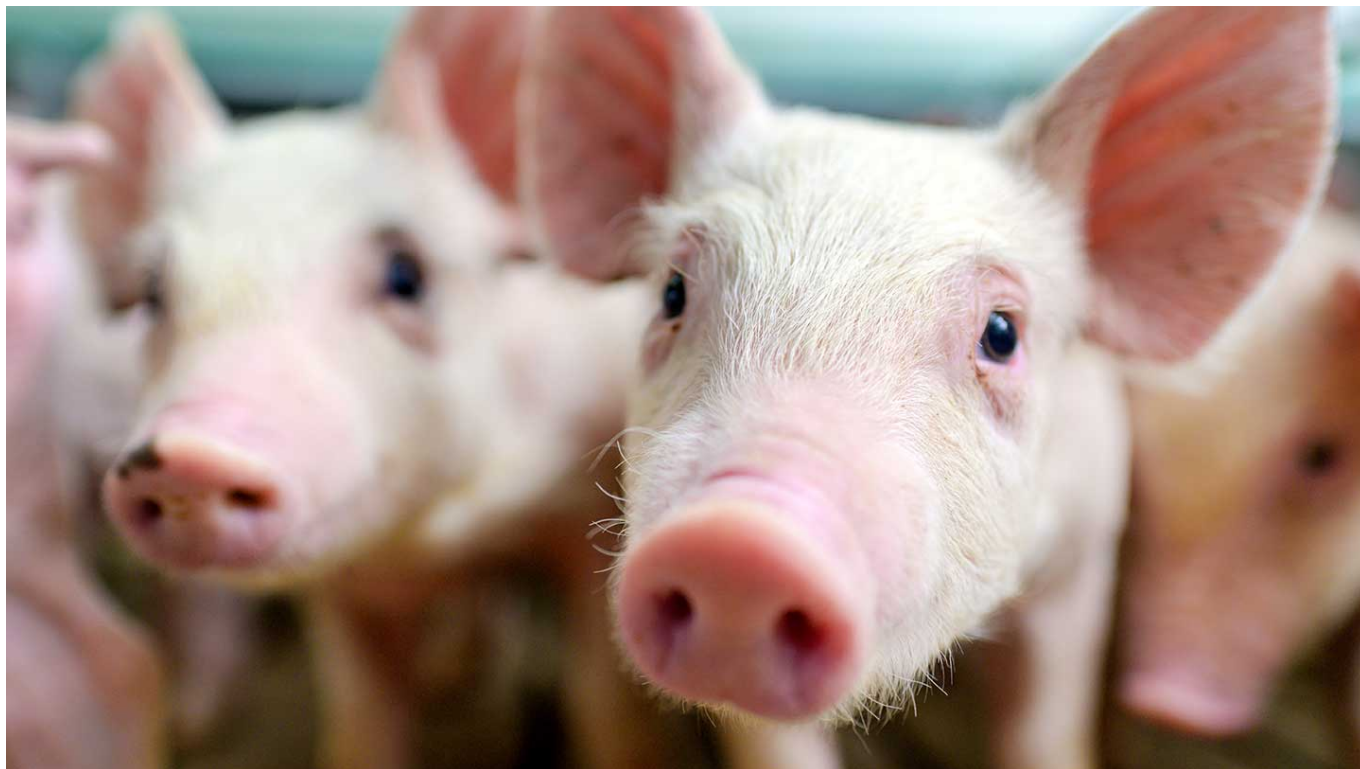
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Minimizing Collateral Effects of Antibiotic Administration in Swine Farms: A Balancing Act



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We care for our animals, and antibiotics are a crucial component in the management of disease due to susceptible pathogens, supporting animal health and welfare. However, the administration of antibiotics in pig farming has become a common practice to prevent bacterial infections, reduce economic losses, and increase productivity.

All antibiotic applications have collateral consequences of significance, bringing a deeper consideration to their non-essential application. This article aims to challenge the choice to administer antibiotics by exploring the broader impact that antibiotics have on animal and human health, economies, and the environment.

Antibiotics disrupt microbial communities

Antibiotics do not specifically target pathogenic bacteria. By impacting beneficial microorganisms, they disrupt the natural balance of microbial communities within animals. They reduce the microbiota diversity and abundance of all susceptible bacteria – beneficial and pathogenic ones... many of which play crucial roles in digestion, brain function, the immune system, and respiratory and overall health. Resulting microbiota imbalances may present themselves in animals showing health performance changes associated with non-target systems, including the nasal, respiratory, or gut microbiome^{7, 8, 14}. The gut-respiratory microbiome axis is well-established in mammals. [Gut microbiota health](#), diversity, and nutrient supply directly impact respiratory health and function¹³. In pigs specifically, the modulation of the gut microbiome is being considered as an additional tool in the control of respiratory diseases such as PRRS due to the link between the digestion of nutrients, systemic immunity, and response to pulmonary infections¹¹.

The collateral effect of antibiotic administration disrupting not only the microbial communities throughout the animal but also linked body systems needs to be considered significant in the context of optimal animal health, welfare, and productivity.

Antibiotic use can lead to the release of toxins

The consideration of the pathogenesis of individual bacteria is critical to mitigate potential for direct collateral effects associated with antibiotic administration. For example, in cases of toxin producing bacteria, when animals are medicated either orally or parenterally, mortality may increase due to the associated release of toxins when large numbers of toxin producing bacteria are killed quickly².

Modulation of the brain function can be critical

Numerous animal studies have investigated the modulatory role of intestinal microbes on the gut-brain axis. One identified mechanism seen with antibiotic-induced changes in fecal microbiota is the decreased concentrations of hypothalamic neurotransmitter precursors, 5-hydroxytryptamine (serotonin), and dopamine⁵. Neurotransmitters are essential for communication between the nerve cells. Animals with oral antibiotic-induced microbiota depletion have been shown to experience changes in brain function, such as spatial memory deficits and depressive-like behaviors.

Processing of waste materials can be impacted

Anaerobic treatment technology is well accepted as a feasible management process for swine farm wastewater due to its relatively low cost with the benefit of bioenergy production. Additionally, the much smaller volume of sludge remaining after anaerobic processing further eases the safe disposal and decreases the risk associated with the disposal of swine waste containing residual antibiotics⁴.

The excretion of antibiotics in animal waste, and the resulting presence of antibiotics in wastewater, can impact the success of anaerobic treatment technologies, which already could be demonstrated by several studies^{6, 11}. The degree to which antibiotics affect this process will vary by type, combination, and concentration. Furthermore, the presence of antibiotics within the anaerobic system may result in a population shift towards less sensitive microbes or the development of strains with antibiotic-resistant genes^{1, 12}.

Antibiotics can be transferred to the human food chain

[Regulatory authorities](#) specify detailed withdrawal periods after antibiotic treatment. However, residues of antibiotics and their metabolites may persist in animal tissues, such as meat and milk, even after this period. These residues can enter the human food chain if not adequately monitored and controlled.

Prolonged exposure to low levels of antibiotics through the consumption of animal products may contribute to the emergence of antibiotic-resistant bacteria in humans, posing a significant public health risk.

Contamination of the environment

As mentioned, the administration of antibiotics to livestock can result in the release of these compounds into the environment. Antibiotics can enter the soil, waterways, and surrounding ecosystems through excretions from treated animals, inappropriate disposal of manure, and runoff from agricultural fields. Once in the environment, antibiotics can contribute to the selection and spread of antibiotic-resistant bacteria in natural bacterial communities. This contamination poses a potential risk to wildlife, including birds, fish, and other aquatic organisms, as well as the broader ecological balance of affected ecosystems.

Every use of antibiotics can create resistance

One of the widely researched concerns associated with antibiotic use in livestock is the development of antibiotic resistance. The development of AMR does not require prolonged antibiotic use and, along with other collateral effects, also occurs when antibiotics are used within recommended therapeutic or preventive applications.

Gene mutations can supply bacteria with abilities that make them resistant to certain antibiotics (e.g., a mechanism to destroy or discharge the antibiotic). This resistance can be transferred to other microorganisms, as seen with the effect of carbadox on *Escherichia coli*⁵ and *Salmonella enterica*² and the carbadox and metronidazole effect on *Brachyspira hyodysenteriae*¹⁵. Additionally, there is an indication that the zinc resistance of *Staphylococcus* of animal origin is associated with the methicillin resistance coming from humans³.

Consequently, the effectiveness of antibiotics in treating infections in target animals becomes compromised, and the risk of exposure to resistant pathogens for in-contact animals and across species increases, including humans.

Alternative solutions are available

To successfully minimize the collateral effects of antibiotic administration in livestock, a unified strategy with support from all stakeholders in the production system is essential. The European Innovation Partnership – Agriculture⁹ concisely summarizes such a process as requiring...

1. Changing human mindsets and habits: this is the first and defining step to successful [antimicrobial](#) reduction
2. Improving pig health and welfare: Prevention of disease with optimal husbandry, hygiene, [biosecurity](#), vaccination programs, and [nutritional support](#).
3. Effective antibiotic alternatives: for this purpose, [phytomolecules](#), pro/pre-biotics, organic acids, and immunoglobulins are considerations.

In general, implementing responsible antibiotic stewardship practices is paramount. This includes limiting antibiotic use to the treatment of diagnosed infections with an effective antibiotic, and eliminating their use as growth promoters or for prophylactic purposes.

Keeping the balance is of crucial

importance

While antibiotics play a crucial role in ensuring the health and welfare of livestock, their extensive administration in the agricultural industry has collateral effects that cannot be ignored. The development of antibiotic resistance, environmental contamination, disruption of microbial communities, and the potential transfer of antibiotic residues to food pose significant challenges.

Adopting responsible antibiotic stewardship practices, including veterinary oversight, disease prevention programs, optimal animal husbandry practices, and [alternatives to antibiotics](#), can strike a balance between animal health, efficient productive performance, and environmental and human health concerns.

The collaboration of stakeholders, including farmers, veterinarians, policymakers, industry and consumers, is essential in implementing and supporting these measures to create a sustainable and resilient livestock industry.

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