THE IMPACT OF A FEED ADDITIVE MIXTURE CONSISTING OF YEAST CELL WALLS AND BUTYRIC ACID ESTERS ON FATTENING PIG CARCASSES AND MEAT QUALITY

Asta Racevičiūtė-Stupelienė[1]*, Monika Nutautaitė[1], Virginijus Slausgalvis[2], Vilma Vilienė[1]

[1]Institute of Animal Rearing Technologies, Veterinary Academy, Lithuanian University of Health Sciences, Tilžės str. 18, LT-47181 Kaunas, Lithuania

[2]Innov ad nv/sa, Postbaan 69, 2910 Essen, Belgium

Abstract

Nowadays, numerous countries are researching feed additives utilisation in pig feed to improve the feed's biological value, increase pig productivity, and increase disease resistance, enhancing pork quality. So, the aim of this study was to determine the influence of a feed additive mixture consisting of yeast cell walls and butyric acid esters on the quality of carcasses and pork from fattening pigs. The feeding test was performed with 32 fattening pigs (65-d-old crossbreeds), which were divided into 2 groups with 4 replicate pens: the control group was fed standard compound feed; the experimental group was fed standard compound feed + 2 kg/t feed additive mixture containing yeast cell walls and butyric acid esters. Pig productivity, muscularity, and fat tissue percentages were assessed during the test. At the end of the trial (179-d-old), 5 fattening pigs were randomly selected from each group and slaughtered; pork carcasses and physico-chemical features were evaluated. The slaughter data of fattening pigs revealed that the carcass weight, carcass yield, longest back muscle area, bacon, and carcass half lengths of the fattening pigs in the experimental group were higher by 1% and 2% compared to the control. However, the feed additive mixture had no significant effect on slaughter data or pork physical or chemical features since no significant difference between the experimental and control groups was discovered (P>0.05). The only indicator of chemical composition that was significantly affected was the ash, which was found to be 0.22% higher in the experimental group compared to the control (P<0.05). According to the obtained results, it can be concluded that the additive, consisting of yeast cell walls and butyric acid esters, used in fattening pigs feed, has no influence on the quality of pork, but it also does not degrade it.

Keywords: *yeast cell walls, butyric acid esters, SCFA, pork, physico-chemical features*

1. INTRODUCTION

Pig farming is one of the main branches of livestock farming in Lithuania. In general, pork accounts for about 50% of the total meat production balance. Pigs have been raised in Lithuania for over 3000 years (Stankevičienė *et al.,* 2008), but modern livestock farming presents new and often complex challenges for animal nutrition specialists and their farmers. As possibilities expand, farmers have a need to safely and economically increase their production while improving the quality of their products. Firstly, the final quality depends on the productivity of the animals, which is influenced by their digestive processes and overall health. Therefore, the influence of the animal diets on their digestive processes and nutritional needs must be taken into account.

Animal-derived food products occupy an important place in the diet of Lithuanian residents as a source of complete proteins, essential amino acids, biologically important fatty acids, fat-soluble vitamins, macro- and microelements, and other important nutritional components. The quality of meat is characterised by safety and sensory indicators, chemical composition, and physical properties (pH, colour, water-holding capacity, texture, completeness of meat proteins, etc.). These indicators are influenced by the species, breed, individual characteristics, sex, age, farming technologies, slaughtering, and freshness of the meat (Garmienė *et al.,* 2010). Moreover, consumers highly value lean, high-biological-value, juicy meat with good taste and culinary properties (Kumar *et al.,* 2017). To meet these expectations, various additives can be used in animal feed, including pig feed, to enrich their diet. Feed additives are materials or preparations that improve feed digestion, promote livestock productivity, meet their nutritional needs at different growth stages, and reduce the harmful effects of animal food metabolites (excreta) on the environment (Tona, 2018). Data on how various pig feed additives affect pig metabolism and the required dosages for pigs of different ages to achieve optimal results are essential because we ourselves consume these products. It is essential to consider that the additives added to feed should be natural, with no residues remaining in the final product and no adverse impact on consumer health (Vilas-Boas, Pintado and Oliveira, 2021). Additionally, it is currently crucial to use cheaper food materials in pig feed and ensure that the pig's body absorbs them as efficiently as possible.

In recent years, many countries have intensified research on how to use various feed additives (fermentative preparations, organic acids, and prebiotics) in pig feed, which can improve the biological value of feed, increase pig productivity, and increase disease resistance (Lin *et al.,* 2020; Chlebicz-Wojcik and Slizewska, 2020; Płacheta *et al.,* 2022). Due to their antibacterial, anti-inflammatory, and proliferative properties, feed additives are a potential alternative to antibiotic growth promoters (Pandey, Kumar and Saxena,2019). One potential feed additive mixture for improving pig growth performance and meat quality consists of yeast cell walls, and butyric acid esters. Yeast cell walls have been shown to improve nutrient digestibility and gut health in pigs (Lee *et al.,* 2021), while butyric acid esters can enhance intestinal morphology and function (Li *et al.,* 2023). Additional sodium calcium aluminosilicate in the feed, on the other hand, can bind to harmful toxins in the feed and reduce their negative impact on pig health (Elliott, Connolly and Kolawole, 2020). By combining these additives, pig farmers may be able to achieve better growth rates and meat quality, as well as reduce the risk of negative health effects from toxins in the feed. However, further research is needed to fully understand the potential benefits and optimal dosages of this feed additive mixture. So, the aim of this study was to determine the influence of a feed additive mixture consisting of yeast cell walls and butyric acid esters on the quality of carcasses and pork from fattening pigs.

2. MATERIALS AND METHODS

2.1. Animals and feeding trial

The pigs for fattening were kept in stalls, and their keeping conditions were in accordance with Council Directive 2008/120/EC of 18 December 2008, which lays down minimum standards for the protection of pigs. The feeding trial was conducted using thirty-two crossbreed fattening pigs (65-d-old), which were individually weighed and randomly assigned to two dietary treatments with four replicate pens. The pigs were fed *ad libitum* with a standard compound diet (**Control group**) and standard compound diet supplemented with 2 kg/t feed additive mixture containing yeast cell walls and butyric acid esters (**Experimental group**). The data recorded during the feeding trial: live weight at 65, 96, 128, 153 and 179 days from the start of the study, average daily gains (ADG), and feed conversion ratio (FCR) during the periods 65–96, 96–128, 128–153, 153-179, and from the start of the study (65–179 days).

2.2. Slaughter performance and sample collection

Before the pigs were slaughtered, their fat thickness and muscularity were measured using ultrasound equipment Piglog-105 (Frontmatec Group, Kolding, Denmark). The measurements included two assessments of fat thickness (in 2 points) and the thickness of the *M. longissimus dorsi*.

At the end of the trial (179-d-old), 5 fattening pigs were selected and slaughtered from each group, totaling 10 pigs. The slaughter was conducted in commercial slaughter house according to standard procedures, slaughter performance was evaluated, and samples were taken from the *M. longissimus dorsi* between the 12th and last rib to analyse physico-chemical properties (n=5 samples/group).

2.3. Physico-chemical composition analysis

To assess the colour changes in *M. longissimus dorsi* muscles, samples were allowed to oxygenate at 4°C for 1 hour after slaughter and then were measured using a Minolta colorimeter CR-300® (Minolta Camera Co., Osaka, Japan) with illuminant D65 and a 0° observer according to the lab system, which includes the L*, a*, and b* values indicating lightness, redness, and yellowness, respectively.

Further, the samples were subjected to three tests to determine drip loss, water holding capacity and cooking loss. Drip loss was measured using the method outlined by Honikel (2009). The tenderness (shear force) of *M. longissimus dorsi* muscle was evaluated according to the Warner-Bratzler cutting power method (American Meat Science Association 2016). Water holding capacity was determined using the pressing method (Zamorano and Gambaruto, 1997). Lastly, cooking loss was measured according to Honikel's methodology (1998).

The chemical analysis of the muscle samples was carried out using standard methods. The dry matter was determined by heating the samples at 105ºC until they reached a constant weight. The fat content was extracted using a Soxtec system with petrol ether at 40–60 °C. The protein content was determined by the Kjeldahl method, as described by King-Brink and Sebranek (1993). The ash content was determined through incineration of the samples in a furnace at 600°C, following the procedure outlined in AOAC (Horwitz, 2005).

2.4. Statistical analysis

The data obtained during the study were analysed using SPSS for Windows, version 25.0 (IBM Corp., released in 2017; Armonk, NY, USA). Prior to data analysis, the normality of the data was determined using the Kolmogorov-Smirnov test. For normally distributed data, a parametric independent T-test was performed on all data obtained during each trial period to identify any differences among the different groups. Statistical significance was defined as a P value less than 0.05 (P<0.05).

3. RESULTS

At the onset of the trial, the weights of the experimental and control groups of pigs were equivalent (Figure 1). However, at 128 days of age, the pigs in the experimental group exhibited a weight increase of 5% relative to the control. By 153 days of age, the experimental group demonstrated a 4% greater weight gain than the control group, owing to the influence of a feed additive mixture. Finally, at the conclusion of the experiment (i.e., 176-d-old), the experimental group had a 2% greater weight gain relative to the control group. Notably, despite these observations, the live weight outcomes between the groups did not exhibit a statistically significant divergence (P>0.05).

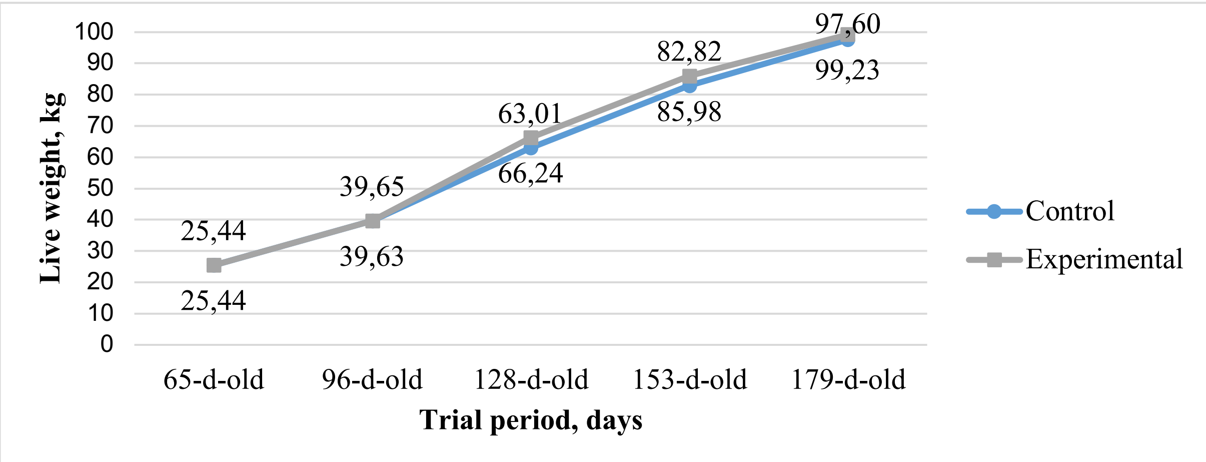

Fig. 1. The impact of a feed additive mixture consisting of yeast cell walls and butyric acid esters on the weight of fattening pigs (65-179 days)

Table 1 presents data on the average daily gain (ADG) and feed conversion ratio (FCR) of fattening pigs fed with 2 kg/t of feed additive. Results showed that during the first growth period (65–96 days), the experimental group exhibited a 6% greater ADG compared to the control group. In the second growth period (96–128), the experimental group showed an 18% greater ADG. However, during the third growth period (128–153 days), the ADG of the experimental group pigs was not significantly different from that of the control. During the final growth period, the ADG of the experimental group of pigs was 11% lower than that of the control group. Overall, when considering the whole trial period, the experimental group's average daily weight gain was 6% higher than that of the control group. However, no statistically significant differences were found between the two groups during any of the growth periods (*P*>0.05). The same trend was repeated, and after evaluating the FCR indicators, no significant influence of the feed additive mixture consisting of yeast cell walls and butyric acid esters was discovered (*P*>0.05).

	ADG, kg		FCR, kg/kg	
Feeding period	**Control**	**Experimental**	**Control**	**Experimental**
I feeding period (65–96 days)	0.425	0.451	1.89	2.05
II feeding period (96–128 days)	0.730	0.861	2.73	2.45
III feeding period (128–153 days)	0.793	0.789	3.53	3.55
IV feeding period (153–179 days)	0.731	0.652	3.52	3.77
Whole (65–179 days)	0.629	0.669	2.19	2.13

Table 1. The impact of a feed additive mixture consisting of yeast cell walls and butyric acid esters on average daily gain (ADG) and feed conversion ratio (FCR) of fattening pigs

According to the data presented in Table 2, after measuring the fat and muscle thickness of the pigs as well as calculating the percentage of muscularity using the formula encoded in the Piglog 105 apparatus, the fat thickness of the experimental group's pigs was 6% thinner at the 1st point and 8% thinner at the 2nd point compared to the control group's pigs. Furthermore, the experimental group's muscle thickness was 1% thinner than the control group's pigs. However, the feed additive did not have a significant impact on muscularity, as the obtained data were statistically unreliable (*P*>0.05).

		Fat thickness, mm			
	Weight, kg	**1st point**	**2nd point**	**Muscles thickness, mm**	**Muscularity, %**
Control	102.57±1.78	13.57±0.97	12.71±0.77	53.14±0.98	58.11±0.87
Experimental	102.14±2.59	12.71±0.56	11.71±0.87	52.43±2.56	58.93±0.94

Table 2. The impact of a feed additive mixture consisting of yeast cell walls and butyric acid esters on fattening pigs muscularity and fat thickness (179-d-old)

After performing the control slaughter of fattening pigs, it was determined that the carcass weight, carcass yield, area of the longest back muscle (*M. longissimus dorsi*), and length of the bacon half of the experimental group pigs were 1% greater, and the length of the carcass half was 2% longer compared to the control group (*P*>0.05) (Table 3).

Item	Control	Experimental
Weight before slaughter, kg	102.14±2.07	102.14±2.58
Carcass weight, kg	71.14±1.32	72.14±1.79
Carcass yield, %	69.84±2.18	70.86±2.57
Area of *M. longissimus dorsi* muscle, cm²	45.70±1.41	46.07±1.46
Carcass half length, cm	96.57±1.39	98.29±0.90
Bacon half length, cm	82.14±0.80	82.86±0.60

Table 3. The impact of a feed additive mixture consisting of yeast cell walls and butyric acid esters on fattening pigs slaughter performance (179-d-old)

According to the chemical analysis of the meat, the feed additive mixture consisting of yeast cell walls and butyric acid esters (experimental group) resulted in a higher content of dry matter by 0.95%, protein by 0.24%, and intramuscular fat by 0.49% compared to the control group (P>0.05) (Table 4). The only significant difference between the groups was found in the ash content, which was 0.22% higher in the experimental group than in the control group (P<0.05).

Item	Control	Experimental
Dry matter, %	26.70±0.55	27.65±0.19
Protein, %	23.85±0.50	24.09±0.42
Intramuscular fat, %	1.62±0.14	2.11±0.35
Ash, %	1.23±0.02	1.45±0.08*
Drip loss, %	6.28±0.64	6.45±1.03
Water holding capacity, %	62.92±0.82	63.83±0.39
Cooking loss, %	22.62±0.93	20.54±1.77
Tenderness, kg/cm^2	2.21±0.14	2.45±0.27
Colour by coordinates		
L*	54.34±1.25	52.55±0.99
a*	14.14±0.26	13.98±0.39
b*	7.38±0.50	6.76±0.65

Note, *Means significant differences between groups (P<0.05).

Table 4. The impact of a feed additive mixture consisting of yeast cell walls and butyric acid esters on physico-chemical composition of *M. longissimuss dorsi* muscle of fattening pigs

Upon analysing the physical properties of the *longissimus dorsi* muscle of pigs, the findings indicated that the drip loss, water holding capacity, and tenderness of meat from the experimental group were respectively higher by 0.17%, 0.91%, and 0.24% compared to the samples from the control group (Table 4). Additionally, cooking losses were lower by 2.08% in the experimental group. However, it should be noted that these differences were not statistically significant (P>0.05). The brightness and yellowness according to colour coordinates of fresh samples from the experimental group were 8% lower, and the redness was 1% lower compared to the samples from the control group.

4. DISCUSSION

The present study investigated the effects of a feed additive mixture containing yeast cell walls and butyric acid esters on pig growth performance. The results demonstrated that the experimental group had increased weight by 5% by the middle of the feeding trial. The weight gain advantage persisted at 153 days of age, with the experimental group exhibiting a 4% greater weight gain compared to the control group. At the end of the trial, the experimental group had a 2% greater weight gain relative to the control group. Therefore, all these differences were not statistically significant. However, these findings suggest that the feed additive mixture containing yeast cell walls and butyric acid esters can potentially enhance pig growth performance. The mechanisms underlying this effect may involve several factors, including improved gut health, enhanced nutrient utilisation, and an increase in growth-promoting hormones. Yeast cell walls are known to improve gut health by providing a source of prebiotic fibre that stimulates the growth of beneficial gut bacteria (Rastall *et al.,* 2022). These beneficial bacteria, in turn, produce short-chain fatty acids such as butyric acid that can promote gut health and improve nutrient absorption. Butyric acid esters, on the other hand, can stimulate the production of growth-promoting hormones such as insulin-like growth factor 1 (IGF-1) (Gomez-Osorio *et al.,* 2021), which can promote muscle growth and enhance nutrient utilisation. However, the lack of statistical significance at the conclusion of the experiment may be attributed to several factors, such as individual variation in pig growth and the possibility of environmental factors influencing the results. Future studies with larger sample sizes and longer durations are warranted to further investigate the effects of this feed additive mixture on pig growth performance and explore potential mechanisms underlying its effects.

Average daily gain (ADG) and feed conversion ratio (FCR) are important indicators of the growth and economic efficiency of pig farming (Rocadembosch *et al.,* 2016). ADG reflects the daily weight gain of pigs during the rearing period, and a higher ADG indicates better growth performance. FCR, on the other hand, represents the amount of feed required to produce a unit of body weight gain, and a lower FCR indicates better feed efficiency. Improving ADG and FCR can lead to faster pig growth, reduced feed costs, and improved profitability for pig farmers (Song and Miller, 2002). Therefore, these indicators are crucial in evaluating the success of pig production and in making decisions related to pig feed and management. However, after analysing the growth performance of fattening pigs fed with a feed additive mixture containing yeast cell walls and butyric acid esters, it was found that there was no statistically significant difference between the experimental and control groups in terms of ADG or FCR. Although the experimental group did exhibit greater ADG during the first and second growth periods, the effect was not significant during the entire trial period. Furthermore, there was no significant influence of the feed additive mixture on FCR indicators, suggesting that the additive did not significantly affect the efficiency of feed utilisation in the pigs.

The study demonstrated that the addition of a feed supplement containing yeast cell walls and butyric acid esters had a positive impact on reducing fat thickness in pigs. The results suggest that the feed additive may have promoted fat mobilisation and reduced fat deposition in the pigs. The potential mechanism for this effect may be related to the ability of butyric acid esters to stimulate the growth of beneficial gut bacteria, which can lead to improved gut health, nutrient absorption and utilisation, and lipid metabolism regulation, ultimately leading to reduced fat deposition (Tugnoli *et al.,* 2020). Additionally, yeast cell walls have beneficial effects on gut health and immune-modulating properties, potentially contributing to the observed reduction in fat thickness (Broadway, Carroll and Sanchez, 2015). The supplement did not have a significant impact on muscularity, but the observed slight reduction in muscle thickness may have been due to individual variation or differences in the pigs' environment or diet as well.

Slaughter performance is an important parameter for assessing the efficiency and profitability of pig production, which includes evaluating the economic value of slaughtered pigs and determining the profitability of the farm. The carcass yield is an essential measurement to consider, as it reflects the proportion of the animal's live weight that is converted into a carcass after slaughter (Flachowsky and Kamphues, 2012). Moreover, the quality of the meat also plays a crucial role in slaughter performance, as it determines the market value of the meat. In the present study, the feed additive mixture containing yeast cell walls and butyric acid esters did not show any statistically significant effects on the carcass weight, carcass yield, area of the longest back muscle, or length of the bacon half of the experimental group pigs compared to the control group. However, it is noteworthy that the experimental group's pigs had a 1% greater carcass weight and carcass yield, suggesting a potential positive impact of the feed additive on meat production. Furthermore, the 2% longer length of the carcass half in the experimental group may indicate a positive effect of the feed additive on the morphology of the pig carcass.

Meat physico-chemical properties are essential for consumers as they significantly impact the meat's sensory attributes, including colour, texture, juiciness, and flavour (Bostami *et al.,* 2022). Pork is no exception. The chemical composition of pork, including protein, fat, and water content, directly affects its nutritional value and sensory characteristics (O'Neill *et al.,* 2019). The properties of meat, such as drip loss, water holding capacity, tenderness, and cooking losses, also play a crucial role in determining the quality and consumer acceptance of pork products. Therefore, understanding the physico-chemical properties is crucial for the pork industry to produce high-quality and desirable pork products that meet the consumers' expectations. The present study investigated the effects of a feed additive mixture consisting of yeast cell walls and butyric acid esters on the chemical and physical properties of pork meat. However, the results showed that the experimental group exhibited higher contents of dry matter, protein, and intramuscular fat in the meat compared to the control group. These findings are in line with previous studies indicating that butyric acid esters could improve the protein and fat metabolism of pigs (Tugnoli *et al.,* 2020; Ficagna *et al.,* 2022; Zeng *et al.,* 2023). Moreover, significant increased ash content in the experimental group's meat may be attributed to the yeast cell walls' effect on mineral absorption (Afzal *et al.,* 2022). The higher water holding capacity and lower cooking losses observed in the experimental group's meat suggest that the feed additive might have improved the meat's ability to retain water, thus enhancing its texture and tenderness. However, the differences in drip loss and tenderness were not statistically significant. Regarding colour coordinates, the meat from the experimental group was less bright and less yellow, which might be due to the higher fat content, as fat has a yellowish tint. Overall, the findings of this study suggest that the feed additive mixture consisting of yeast cell walls and butyric acid esters has the potential to improve the chemical and physical properties of pork meat.

5. CONCLUSIONS

The investigation into the feed additive mixture composed of yeast cell walls and butyric acid esters revealed that it did not elicit statistically significant effects on the growth, carcass quality, and meat quality of fattening pigs. Although some variations were observed, such as higher weight gain and thinner fat thickness, and improved physical properties of meat, such as higher water holding capacity and tenderness, these differences did not attain practical significance. The only significant impact of the feed additive mixture was observed in the ash content increase in *M. longissimus dorsi* muscle. Furthermore, the findings highlight the need for further research to confirm the potential benefits of the feed additive mixture and establish the optimal dosage required to achieve these effects.

REFERENCES

1. Afzal, N, Mona Hassan, S, Sharif Mughal, S, Pando, A and Rafiq, A 2022, "Control of Aflatoxins in Poultry Feed by Using Yeast", *American Journal of Chemical and Biochemical Engineering,* vol., no. 1, pp. 21.
2. American Meat Science Association. 2016. Research guide-lines for cookery, sensory evaluation and instrumental ten-derness measurements of fresh meat. 2nd ed., Version1.02. Chicago (IL): American Meat Science Association.

3. Bostami, AR, Khan, M, Selim, A, Hossain, M and M Khairunnesa 2022, "Physico-chemical parameters and sensory attributes of different chicken meat of consumer's choice from poultry market", *Meat Research,* vol., no. 2.
4. Broadway, PR, Carroll, JA and Sanchez, NCB 2015, "Live Yeast and Yeast Cell Wall Supplements Enhance Immune Function and Performance in Food-Producing Livestock: A Review", *Microorganisms,* vol. 3, no. 3, pp. 417-427.
5. Chlebicz-Wojcik, A and Slizewska, K 2020, "The Effect of Recently Developed Synbiotic Preparations on Dominant Fecal Microbiota and Organic Acids Concentrations in Feces of Piglets from Nursing to Fattening", *Animals (Basel),* vol. 10, no. 11, pp. 1999.
6. Elliott, CT, Connolly, L and Kolawole, O 2020, "Potential adverse effects on animal health and performance caused by the addition of mineral adsorbents to feeds to reduce mycotoxin exposure", *Mycotoxin research,* vol. 36, no. 1, pp. 115-126.
7. Ficagna, CA, Galli, GM, Zatti, E, Sponchiado, BM, Cecere, BGDO, Deolindo, GL, Tarasconi, L, Horn, VW, Mendes, RE, Bissacotti, BF, Schetinger, MRC, Boiago, MM and da Silva, AS 2022, "Butyric acid glycerides in the diet of broilers to replace conventional growth promoters: effects on performance, metabolism, and intestinal health", *Archives of animal nutrition,* vol. 76, no. 3-6, pp. 191-204.
8. Flachowsky, G and Kamphues, J 2012, "Carbon Footprints for Food of Animal Origin: What are the Most Preferable Criteria to Measure Animal Yields?", *Animals (Basel),* vol. 2, no. 2, pp. 108-126.
9. Garmienė, G, Jasutienė, I, Zaborskienė, G, Mieželienė, A, Alenčikienė, G and Miliauskienė, I 2010, "Lietuvos rinkoje parduodamos kiaulienos nugarinės kai kurių rodiklių palyginimas", *Veterinarija ir Zootechnika,* vol. 52, no. 74, pp. 21-23.
10. Gomez-Osorio, L, Yepes-Medina, V, Ballou, A, Parini, M and Angel, R 2021, "Short and Medium Chain Fatty Acids and Their Derivatives as a Natural Strategy in the Control of Necrotic Enteritis and Microbial Homeostasis in Broiler Chickens", *Frontiers in veterinary science,* vol. 8, pp. 773372.
11. Honikel, KO 2009, "Water-holding capacity of meat" *In Muscle Development of Livestock Animals: Physiology, Genetics and Meat Quality* Wallingford, UK: CABI, pp. 389-400.
12. Honikel, KO 1998, "Reference methods for the assessment of physical characteristics of meat", *Meat science,* vol. 49, no. 4, pp. 447-457.
13. Horwitz, W 2005, *Official methods of analysis of AOAC International*. 18. ed. , current through rev. 2, 2007 edn. Gaithersburg, Maryland, USA: AOAC International, pp. 24-36 .
14. King-Brink, M and Sebranek, JG 1993, "Combustion method for determination of crude protein in meat and meat products: collaborative study", *Journal of AOAC International,* vol. 76, no. 4, pp. 787-793.
15. Kumar, P, Chatli, MK, Mehta, N, Singh, P, Malav, OP and Verma, AK 2017, "Meat analogues: Health promising sustainable meat substitutes", *Critical reviews in food science and nutrition,* vol. 57, no. 5, pp. 923-932.
16. Lee, JJ, Kyoung, H, Cho, JH, Choe, J, Kim, Y, Liu, Y, Kang, J, Lee, H, Kim, HB and Song, M 2021, "Dietary Yeast Cell Wall Improves Growth Performance and Prevents of Diarrhea of Weaned Pigs by Enhancing Gut Health and Anti-Inflammatory Immune Responses", *Animals (Basel),* vol. 11, no. 8, pp. 2269.
17. Li, H, Zhang, Y, Xie, J, Wang, C, Yi, D, Wu, T, Wang, L, Zhao, D and Hou, Y 2023, "Dietary Supplementation with Mono-Lactate Glyceride Enhances Intestinal Function of Weaned Piglets", *Animals (Basel),* vol. 13, no. 8, pp. 1303.
18. Lin, B, Yan, J, Zhong, Z and Zheng, X 2020, "A Study on the Preparation of Microbial and Nonstarch Polysaccharide Enzyme Synergistic Fermented Maize Cob Feed and Its Feeding Efficiency in Finishing Pigs", *BioMed research international,* 2020, pp. 8839148-11.

19. O'Neill, CM, Cruz-Romero, MC, Duffy, G and Kerry, JP 2019, "Comparative effect of different cooking methods on the physicochemical and sensory characteristics of high pressure processed marinated pork chops", *Innovative food science & emerging technologies,* vol. 54, pp. 19-27.

20. Pandey, AK, Kumar, P and Saxena, MJ 2019, "Feed Additives in Animal Health" *Nutraceuticals in Veterinary Medicine* Cham: Springer International Publishing, pp. 345-362.

21. Płacheta, B, Motyl, I, Berłowska, J and Mroczyńska-Florczak, M 2022, "The Use of Fermented Plant Biomass in Pigs Feeding", *Sustainability (Basel, Switzerland),* vol. 14, no. 21, pp. 14595.

22. Rastall, RA, Diez-Municio, M, Forssten, SD, Hamaker, B, Meynier, A, Moreno, FJ, Respondek, F, Stah, B, Venema, K and Wiese, M 2022, "Structure and function of non-digestible carbohydrates in the gut microbiome", *Beneficial microbes,* vol. 13, no. 2, pp. 95-168.

23. Rocadembosch, J, Amador, J, Bernaus, J, Font, J and Fraile, LJ 2016, "Production parameters and pig production cost: temporal evolution 2010–2014", *Porcine Health Management,* vol. 2, no. 1, pp. 11.

24. Song, Y and Miller, GY 2002, "Effects of Marketing Decisions on Net Present Value of Pork Production for Independent and Allied Swine Producers", *Applied economic perspectives and policy,* vol. 24, no. 1, pp. 181-195.

25. Stankevičienė, M, Stankevičius, A, Stankevičius, H, Liutkevičienė, V, Černauskienienė, J, Šakalienė, J and Petkevičius, S 2008, "Kiaulių reprodukcinio ir kvėpavimo sindromo paplitimas, veislių jautrumas virusui", *Veterinarija ir Zootechnika,* vol. 42, no. 64, pp. 71-80.

26. Tona, GO 2018, "Animal Husbandry and Nutrition" *Current and Future Improvements in Livestock Nutrition and Feed Resources* IntechOpen, pp. 147-152.

27. Tugnoli, B, Giovagnoni, G, Piva, A and Grilli, E 2020, "From Acidifiers to Intestinal Health Enhancers: How Organic Acids Can Improve Growth Efficiency of Pigs", *Animals,* vol. 10, no. 1, pp. 134.

28. Vilas-Boas, AA, Pintado, M and Oliveira, ALS 2021, "Natural Bioactive Compounds from Food Waste: Toxicity and Safety Concerns", *Foods,* vol. 10, no. 7, pp. 1564.

29. Zamorano, J and Gambaruto, M 1997, "Contribution to improving the meat water holding capacity test by the filter paper press method. A comparison of three methods for measuring areas", *Meat science,* vol. 46, no. 1, pp. 129-137.

30. Zeng, X, Li, S, Liu, L, Cai, S, Ye, Q, Xue, B, Wang, X, Zhang, S, Chen, F, Cai, C, Wang, F. and Zeng, X 2023, "Role of functional fatty acids in modulation of reproductive potential in livestock", *Journal of Animal Science and Biotechnology,* vol. 14, no. 1, pp. 24.