

# The effects of inulin supplementation in diets of pigs on growth performance and selected meat quality traits: a systematic review and meta-analysis

A. Zyburt, A. Milczarek\* and K. Tarczyński

University of Siedlce, Institute of Animal Science and Fisheries, B. Prusa 14, 08-110 Siedlce, Poland

**KEY WORDS:** fattening results, inulin, meat quality, meta-analysis, nutrition, pigs

Received: 10 October 2025

Revised: 3 December 2025

Accepted: 8 December 2025

\* Corresponding author:  
e-mail: [anna.milczarek@uws.edu.pl](mailto:anna.milczarek@uws.edu.pl)

**ABSTRACT.** Inulin supplementation has been reported to enhance performance responses in pigs and positively modify the quality of pork. However, the results of research are inconsistent. The present study aimed to quantify the effects of inulin supplementation in diets of pigs on performance traits and selected pork quality traits, using the meta-analytical approach. Data were extracted from 45 studies and analysed using the random-effect model to estimate the effects of inulin on average daily gain (ADG), average daily feed intake (ADFI), feed conversion ratio and selected pork quality traits including initial and ultimate pH (pH<sub>1</sub> and pH<sub>u</sub>), drip loss (DL) and colour. The meta-analysis detected the influence of inulin on ADG and ADFI under several study factors. The inulin supplementation significantly improved ADG in growing-finishing pigs but the stronger effect was detected for the long-chain inulin. The dose of inulin in diet (<3% and ≥3%) enhanced ADG in similar range of the effect. Inulin supplementation decreased ADFI only in weaning pigs. There were no effects of inulin on pH<sub>1</sub>, pH<sub>u</sub> and DL. However, inulin supplementation significantly modified the colour of pork. A trend to increase in redness (a\*) and decrease in yellowness (b\*) was detected in loins of pigs fed with lower (<3%) doses of inulin, nonetheless the application of long-chain inulin may result in increase of lightness (L\*) of meat. In conclusion, the inulin supplementation may enhance ADG and colour characteristics but depend on degree of polarisation and dose.

## Introduction

Pork is the most consumed meat in Europe, however, the shifts in EU consumer attitudes and preferences toward meat may decrease future consumption of pork (OECD, 2023). In Europe, health issues and consumers perceived quality of meat are the most acknowledged reasons for shift in pork consumption (Grunert et al., 2018). With regard to health risks, consumers concern the antimicrobial use in food-producing animals. Although, the European Union has banned all in-feed use of antibiotics, consumers are still concerned about the possibility of antibiotic

residues in meat contributing to antimicrobial resistance (Barrett et al., 2021; Bradford et al., 2021). Furthermore, health-oriented consumers are willing to pay more for free antibiotic pork (Denver et al., 2021; Meerza et al., 2022; Paudel et al., 2022). This perspective has stimulated researchers to search non-antibiotic production strategies focused on the health status improvement and performance of pigs (Patience and Ramirez, 2022). To meet these challenges, non-antibiotic feed additives have become of crucial importance. One of these alternatives are prebiotics, a selectively fermented feed ingredients that result in specific changes in the composition

and/or activity of the gastrointestinal microbiota, thus conferring benefits upon host health (Gibson et al., 2010; Liu et al., 2018).

Inulin-type fructans including inulin, oligofructose and fructo-oligosaccharides (FOS) are the most commonly used prebiotics in monogastric animals nutrition (Liu et al., 2023). Inulin is plant origin polysaccharide present in the tubers and roots of many plant species. In most plants (e.g. wheat, barley, onion, banana, garlic), the inulin content doesn't exceed few percent of fresh weight. The richest in inulin are chicory root and Jerusalem artichoke, containing between 10 and 20% of inulin (Qin et al., 2023). Furthermore, chicory root is the primary source of commercial inulin extracts (Roberfroid, 2007).

Inulin, is a fructan type polysaccharide with the structure constituted with a variable number of fructose units linked by  $\beta$ -(2,1)-fructosyl-fructose bonds. A glucose molecule typically is present at the end of each fructose chain and is linked by an  $\alpha$ -(1,2) bond. The chain length and polydispersity of inulin depends on the plant species and extraction method (Roberfroid, 2005; Apolinario et al., 2014; Shoaib et al., 2016). In native chicory inulin, a number of fructose units varies between 2 and 60. The average degree of polymerisation (DP) is between 10 and 20 (Roberfroid et al., 1998). The inulin from Jerusalem artichoke tubers contains from 3 to 35 fructose units and the average DP of 6 (Luo et al., 2018). The inulin with a less than 10 fructose units is called short chain inulin or fructo-oligosaccharides (Apolinario et al., 2014) whereas inulin with a chain length ranging from 11 to 60 and an average DP of around 25 is called 'high performance' (HP) or long-chain inulin (Niness, 1999). The DP affects both physicochemical properties of inulin and its ability to modify the composition of the intestinal microflora. Furthermore, the DP is often used to characterize commercially available inulin (Roberfroid, 2005).

The application of inulin in diets for pigs has various direct and indirect benefits. These include the regulation of intestinal microbiota via stimulating the growth of bifidobacteria and lactic acid bacteria, the stimulation of immune system and the improvement of mineral absorption (Yasuda et al., 2009; Wang et al., 2020; He et al., 2021). Furthermore, inulin supplementation can exert positive effects on performance traits (Hansen et al., 2002; Grela et al., 2014; Samolińska and Grela, 2017), and pork meat quality including both composition traits and physico-chemical properties of meat (Rosenvold et al., 2001a; Aluwé et al., 2013; Przybylski et al. 2019). However, dietary administration of

inulin has been shown to have different effects on performance and pork quality in different studies. Several studies showed that inulin supplementation improves growth of pigs (Jayasooriya et al., 2009; Hansen et al., 2002; Ponnampalam et al., 2009; Grela et al., 2013; Sobolewska and Grela, 2014; Samolińska and Grela, 2017; Sobol et al., 2018; Grela et al., 2021; Dunshea et al., 2024). In contrast, Nowak et al. (2017) reported that weaned pigs fed 3% inulin diet had significantly lower average daily gain (ADG) than control pigs. Others (Pierce et al., 2005; Øverland et al., 2011; While et al., 2012; Deng et al., 2017; McCormack et al., 2019; Hu et al., 2020) found no effect of inulin supplementation on growth performance of the weaned and growing-finishing pigs.

In pork production, the feeding strategies focus also on improve of various quality dimensions including carcass composition, nutritional, sensory and technological properties of pork. In Europe, consumers have become more aware of pork quality, over the past few decades (Henchion et al., 2014). Therefore, the pork quality has become an important issue for pig production. Although, it has been reported that inulin may affect pork quality, the results are not consistent. Several research (Rosenvold et al., 2001a; Hansen et al., 2002; Rosenvold and Andersen, 2003; Rosenvold et al., 2003; Przybylski et al., 2019) showed that feed supplementation with inulin improved initial or ultimate pH and drip loss (DL). In contrast, Aluwé et al. (2013) reported increase in DL in loins of pigs supplemented with inulin. Furthermore, Sobolewska and Grela (2014) and Grela et al. (2021) found that growing-finishing pigs fed diet with 2% inulin had less red (a\*) and more yellow (b\*) loins than those from control group. Others (Hansen et al., 2008; Jayasooriya et al., 2009; Wang et al., 2019; Dunshea et al., 2024) have found no effect of inulin supplementation on technological properties of pork.

Nutritional responses to the supplementation of inulin in diets of animals have been comprehensively reviewed by several authors (Flickinger et al., 2003; Kozłowska et al., 2016; Birmani et al., 2019). Narrative reviews summarize different primary studies on the topic of interest, however provide evidences from contextual point of view and qualitative assessment of results. Meta-analysis is a statistical method that combines the data from independent studies, often diverging in the magnitude and statistical significance of responses, to obtain a quantitative estimate of the effect of intervention or variable on a defined outcome (Borenstein et al., 2009). Thus, the objective of this study was to

quantify the effects of inulin supplementation in diets of pigs on growth performance and selected meat quality traits.

## Material and methods

A literature search for published studies investigating the influence of dietary inulin on growth performance of pigs and pork meat quality was performed using Science Direct, ProQuest, Scopus, Web of Science, EBSCO and Google Scholar digital databases. A comprehensive search for published studies performed from October 2024 to February 2025. The search was based on following keywords: inulin, chicory, Jerusalem artichoke in combination with pigs, growth, pork, meat quality. Additionally, examined the references cited in articles and reviews to identify eligible studies to potential inclusion to meta-analysis. The eligibility of studies was determined by the following criteria: performed on pigs, provided information on inulin level, published in English or with an English abstract, reported growth performance (average daily gain – ADG; average daily feed intake – ADFI; feed conversion ratio – FCR) and/or meat quality (initial pH - pH<sub>i</sub>; ultimate pH – pH<sub>u</sub>; drip loss – DL; colour) results, quality traits recorded in *longissimus muscle*, provided data that were sufficient for determining the effect size including the number of animals, mean values and the measure of variation expressed as standard deviation (SD) or standard error (SE) for extracted outcomes. Studies were rejected if any one of these criteria was not met. When the effect of dietary inulin supplementation on growth performance or meat quality traits was explored in separate experiments within study, then these experiments with relevant outcomes were treated as separate studies. The screening resulted in the selection of 44 publications with 88 individual experiments (Table 1). The database included the author's name, year of publication, number of pigs in the control and treatment group, breed, production stage, inulin level and source, duration of inulin supplementation, stunning method (electrical or gas stunning with CO<sub>2</sub>) and the mean with corresponding variability measures. Outcomes extracted for meta-analysis included: ADG (kg/day), ADFI (kg/day), FCR (kg/kg), pH<sub>i</sub> measured between 45 min and 60 min after the slaughter, pH<sub>u</sub> measured 24 or 48 h after the slaughter, DL expressed as a percentage of weight loss after 24 or 48 h of storage at 4 °C, meat colour determined in CIE colour system and expressed as

lightness (L\*), redness (a\*) and yellowness (b\*). A summary of the data from studies included in meta-analysis presented in Table 2.

The statistical analysis was performed with PQ-Stat (1.6.4.188, PQstat Software, Poland). The effect size quantifying the amount by which the experimental treatment changes on average the outcome compared with the controls, was computed as the weighted mean difference (WMD). The WMD is a difference in a means between treatment and control, that are weighted by their sample size (Bakbergenuly et al., 2020). In meta-analyses, effect sizes are combined using fixed- or random-effect model (Borenstein et al., 2009; Vesterinen et al., 2014). Fixed-effect models assume the true effect of the treatment is the same for every study (Zlowodzki et al., 2007). However, the results of multiple studies vary due to differences in animals (breeds), treatment parameters or other unknown factors. Thus, the random-effect model, assuming variability between studies, was adopted to estimate the effect size, 95% confidence intervals (95% CI) and statistical significance of the effect (Higgins et al., 2009). A positive estimate of the effect size indicates greater outcomes in the control group, whereas a negative effect size indicates greater outcomes in inulin treatment group. Heterogeneity, defined as inconsistency in the treatment effect across studies, was determined using Cochran's Q test and Higgins's I<sup>2</sup> statistic. A value of I<sup>2</sup> between 25 and 50% reflects low heterogeneity, between 50 and 75% represents moderate, whereas above 75% high heterogeneity (Higgins and Thompson, 2002). To control for heterogeneity, the studies were stratified into groups/subgroups and each subgroup subjected to separate meta-analysis. Sub-group meta-analysis is a common method used to explore sources of heterogeneity or provide estimates of the treatment effect for factors that may influence on the performance and quality outcomes (Richardson et al., 2019). In this research, the studies were stratified into subgroups, differentiated by production state (weaners and growing-finishing pigs) inulin dose, inulin form (standard and long chain inulin) and stunning method (electrical and gas with CO<sub>2</sub>).

## Results

In this research, overall meta-analysis detected, that supplementation with inulin significantly ( $P \leq 0.01$ ) improved ADG and ADFI (Table 3), but with high heterogeneity between studies. In sub-groups, meta-analysis indicated that inulin

**Table 1.** Summary of studies included in meta-analysis

Reference	Growth stage	Inulin dose, %	Inulin form	Duration of intervention, days	Outcomes
Rosenvold et al. (2001a)	Growing-finishing pigs	25	LC	21	ADG, ADFI, FCR, pH <sub>1</sub> , pH <sub>u</sub> , DL, L*, a*, b*
Rosenvold et al. (2001b)	Growing-finishing pigs	25	LC	14	ADG, ADFI, FCR, pH <sub>u</sub> , L*, a*, b*
Hansen et al. (2002)	Growing-finishing pigs	25	LC	21	ADG, ADFI, FCR, pH <sub>1</sub>
Rosenvold et al. (2002)	Growing-finishing pigs	25	LC	22	ADG, ADFI, FCR, pH <sub>1</sub> , pH <sub>u</sub> , DL, L*, a*, b*
Mikkelsen et al. (2003)	Weaning pigs	4	SI	28	ADG, ADFI, FCR
Rosenvold and Andersen (2003)	Growing-finishing pigs	25	LC	14	pH <sub>1</sub> , pH <sub>u</sub> , DL
Rosenvold et al. (2003)	Growing-finishing pigs	25	LC	14	pH <sub>1</sub> , pH <sub>u</sub> , DL
Pierce et al. (2005)	Weaning pigs	1.5	SI	21	ADG, ADFI, FCR
Hansen et al. (2006)	Growing-finishing pigs	16	SI, LC	42	ADG
Yasuda et al. (2006)	Weaning pigs	2, 4	S	24	ADG, ADFI
Hansen et al. (2008)	Growing-finishing pigs	5	SI	14	pH <sub>1</sub> , pH <sub>u</sub> , DL, L*, a*, b*
Wellock et al. (2008)	Weaning pigs	5, 15	SI	14	ADG, ADFI
Halas et al. (2009)	Weaning pigs	8	LC	21	ADG, ADFI, FCR
Jayasooriya et al. (2009)	Growing-finishing pigs	5	SI		ADG, DL, L*
Yasuda et al. (2009)	Weaning pigs	4	S, SI, LC	35	ADG, ADFI
Ponnampalam et al. (2009)	Growing-finishing pigs	5	SI	35	ADG, ADFI, pH <sub>u</sub> , DL, L*, a*, b*
Mair et al. (2010)	Weaning pigs	0.4	SI	28	ADG, ADFI, FCR
Øverland et al. (2011)	Growing-finishing pigs	3, 6, 9	SI	30	ADG, ADFI
Ivarson et al. (2012)	Weaning pigs	5	SI	14	ADG, ADFI, FCR
Jolliff and Mahan (2012)	Weaning pigs	3, 6	SI	35	ADG, ADFI
While et al. (2012)	Growing-finishing pigs	6.3, 4.1, 8.1		7	ADG, ADFI
Aluwé et al. (2013)	Growing-finishing pigs	5	SI	28	pH <sub>u</sub> , DL, L*, a*, b*
Grela et al. (2013)	Growing-finishing pigs	3	LC	100	ADG, ADFI, FCR
Sobolewska and Grela (2014)	Growing-finishing pigs	2	SI	98	ADG, ADFI, FCR, pH <sub>1</sub> , pH <sub>u</sub> , DL, L*, a*, b*
Aluwé et al. (2017)	Growing-finishing pigs	5	LC	21	ADG
Deng et al. (2017)	Growing-finishing pigs	1	SI	38	ADG, ADFI, FCR
Nowak et al. (2017)	Weaning pigs	3	SI	28	ADG, FCR
Samolińska and Grela (2017)	Growing-finishing pigs	1, 2, 3	SI, LC	105	ADG, ADFI
Samolińska et al. (2018)	Growing-finishing pigs	2	SI, LC	98	ADG, ADFI, FCR
Sobol et al. (2018)	Growing-finishing pigs	7	LC	70	ADG, ADFI, FCR
McCormack et al. (2019)	Weaning pigs	3	S	42	ADG, ADFI, FCR
Przybylski et al. 2019)	Growing-finishing pigs	7	LC	40, 70	pH <sub>u</sub> , DL, L*, a*, b*
Samolińska et al. (2019)	Growing-finishing pigs	2	SI, LC	105	ADG, FCR
San Andres et al. (2019)	Weaning pigs	0.025, 0.25	SI	35	ADG, ADFI
Wang et al. (2019)	Growing-finishing pigs	0.5	LC	32	ADG, ADFI, pH <sub>1</sub> , pH <sub>u</sub> , DL, L*, a*, b*
Chen et al. (2020)	Weaning pigs	1		28	ADG, ADFI
Hu et al. (2020)	Growing-finishing pigs	2	SI	28	ADG, ADFI
Wang et al. (2020)	Weaning pigs	0.25, 0.5, 1	LC	21	ADG, ADFI
Grela et al. (2021)	Growing-finishing pigs	2	SI, LC	98	ADG, FCR, pH <sub>1</sub> , pH <sub>u</sub> , DL, L*, a*, b*
Xia et al. (2021)	Weaning pigs	5		72	ADG, ADFI
Lepczyński et al. (2021)	Weaning pigs	2	SI	32	ADG, ADFI
Herosimczyk et al. (2022)	Weaning pigs	2	SI	32	ADG, ADFI
Yang et al. (2023)	Weaning pigs	0.25	SI	28	ADG, ADFI
Dunsha et al. (2024)	Growing-finishing pigs	5	SI	35	ADG, FCR, pH <sub>u</sub> , DL, L*, a*, b*

SI – standard inulin, LC – long chain inulin, S – 50:50 mixture of LC and SI inulin, ADG – average daily gain, ADFI – average daily feed intake, FCR – feed conversion ratio, pH<sub>1</sub> – initial pH, pH<sub>u</sub> – ultimate pH, DL – drip loss, L\* – lightness, a\* – redness, b\* – yellowness

supplementation altered ADG only in G-F pigs. Furthermore, inulin supplementation significantly ( $P \leq 0.01$ ) increased ADG in both dose dependent groups, but these effects differed in narrow range of the effects size and 95% CI. When the data

were split into the two inulin form sub-groups, the larger increase in ADG was detected for LC inulin. For ADFI, significant alterations detected only for weaned pigs. Inulin dose and inulin form had no effect on ADFI. Additionally, none of the factors

**Table 2.** Descriptive statistics of parameters included in meta-analysis

Trait	n	Treatment group									
		control					inulin				
		Mean	SE	Min.	Max.	Median	Mean	SE	Min.	Max.	Median
ADG, kg	39/86	0.692	0.030	0.146	1.122	0.785	0.723	0.025	0.154	1.120	0.841
ADFI, kg	30/62	1.563	0.059	0.218	3.030	1.509	1.651	0.056	0.198	3.320	1.812
FCR, kg/kg	19/37	2.458	0.110	1.460	4.520	2.525	2.435	0.112	1.250	3.460	2.640
pH <sub>i</sub>	9/15	6.488	0.086	6.25	6.66	6.485	6.406	0.098	6.23	6.59	6.42
pH <sub>u</sub>	14/25	5.573	0.049	5.40	6.07	5.55	5.575	0.047	5.41	6.06	5.59
DL, %	13/23	5.528	0.22	2.18	8.77	6.50	5.63	0.20	2.05	8.79	6.60
L*	13/23	54.41	1.49	50.93	57.93	54.17	54.08	1.46	49.78	57.48	54.10
a*	13/23	10.09	0.55	6.89	19.92	8.16	11.67	0.53	7.42	20.54	8.65
b*	13/23	9.93	0.39	1.42	16.80	14.40	8.22	0.29	1.41	16.60	6.20

n – number of studies/experiments, SE – standard error; ADG – average daily gain, ADFI – average daily feed intake, FCR – feed conversion ratio, pH<sub>i</sub> – initial pH, pH<sub>u</sub> – ultimate pH, DL – drip loss, L\* – lightness, a\* – redness, b\* – yellowness

**Table 3.** Summary of the effect sizes of the inulin supplementation on analysed performance traits in random-effect meta-analysis

Trait	Group/subgroup	n	Effect size	SE	95%CI	P-value	I <sup>2</sup> (%)
ADG, kg	Overall	2535	-0.013	0.004	-0.005; -0.022	0.00	94.63
	W	1694	-0.014	0.012	-0.008; -0.037	0.22	92.80
	G-F	841	-0.017	0.003	-0.011; -0.022	0.00	84.05
	ID <3%	854	-0.017	0.03	-0.011; -0.023	0.00	90.18
	ID ≥3%	830	-0.016	0.006	-0.004; -0.026	0.00	73.45
	SI	705	-0.010	0.003	-0.003; -0.017	0.00	84.95
	LC	968	-0.030	0.005	-0.020; -0.043	0.00	81.07
	AFI, kg	Overall	1778	-0.019	0.009	0.001; 0.038	0.03
W		1019	-0.035	0.015	0.065; -0.005	0.02	93.71
G-F		759	-0.008	0.010	0.012; -0.028	0.44	61.31
ID <3%		954	-0.016	0.008	0.001; -0.032	0.056	62.28
ID ≥3%		824	-0.024	0.015	0.006; -0.054	0.12	65.62
SI		968	-0.013	0.008	0.005; -0.030	0.16	52.94
LC		421	-0.037	0.022	0.006; -0.079	0.09	71.78
FCR, kg/kg		Overall	1271	0.009	0.010	0.030; -0.010	0.349
	WP	417	0.017	0.053	0.120; -0.088	0.75	51.17
	G-F	854	0.008	0.008	0.026; -0.008	0.31	9.45
	ID <3%	756	0.008	0.011	0.031; -0.016	0.52	26.25
	ID ≥3%	515	0.010	0.020	0.025; -0.016	0.62	28.17
	SI	776	0.005	0.010	0.025; -0.016	0.64	19.37
	LC	245	0.054	0.051	0.156; -0.046	0.29	46.19

n – number of animals; ADG – average daily gain; ADFI – average daily feed intake; FCR – feed conversion ratio; W – weaning pigs; G-F – growing-finishing pigs; ID <3% – inulin dose in diet below 3%; ID ≥3% – inulin dose in diet equal or higher than 3%; SI – standard inulin; LC – long chain inulin; SE – standard error; 95%CI – confidence interval; I<sup>2</sup> – percentile of total variation due to heterogeneity

employed to stratify the studies showed significant differences in FCR between inulin fed and control pigs. For meat quality traits, overall meta-analysis detected no effect of inulin supplementation on pH<sub>i</sub>, pH<sub>u</sub>, DL, L\* and a\* (Table 4). In sub-groups, none of the factors employed to stratify the studies showed significant effect of dietary inulin on pH<sub>i</sub>, pH<sub>u</sub> and DL. However, inulin supplementation significantly modified L\*, a\* and b\* of pork under the several

study factors. The meta-analysis indicated, that application of dietary inulin in fed of pigs at lower than 3% dose, significantly increased a\* and decreased b\*, whereas at higher doses (≥3%) decreased a\* without the effect on b\*. When the data were split into the two inulin form sub-groups, meta-analysis detected that application of LC inulin significantly increased the lightness (L\*) and redness (a\*) and decreased the yellowness (b\*) of meat,

**Table 4.** Summary of the effect sizes of the inulin supplementation on analyzed meat quality traits in random-effect meta-analysis

Trait	Group/subgroup	n	Effect size	SE	95% CI	P-value	I <sup>2</sup> (%)
pH <sub>i</sub>	Overall	550	0.001	0.030	0.061; -0.058	0.97	61.05
	ID <3%	324	0.056	0.044	0.141; -0.029	0.20	34.68
	ID ≥3%	266	-0.028	0.038	0.046; -0.102	0.46	65.40
	SI	272	0.024	0.031	0.085; -0.037	0.45	0
	LC	278	-0.009	0.046	0.082; -0.102	0.84	76.90
	E	324	0.056	0.044	0.142; -0.029	0.20	34.68
	G	266	-0.027	0.038	0.047; -0.102	0.46	65.40
	Overall	849	-0.015	0.011	0.007; -0.036	0.18	19.50
pH <sub>u</sub>	ID <3%	324	-0.005	0.014	0.023; -0.034	0.71	10.71
	ID ≥3%	525	-0.018	0.015	0.011; -0.046	0.23	14.05
	SI	543	-0.016	0.017	0.012; -0.046	0.27	0
	LC	306	-0.017	0.015	0.018; -0.050	0.36	34.11
	E	543	-0.033	0.022	0.009; -0.077	0.12	0
	G	306	-0.011	0.014	0.017; -0.039	0.46	0
	Overall	665	0.062	0.195	0.445; -0.321	0.75	98.78
	ID <3%	132	0.098	0.066	0.230; -0.032	0.14	0
DL, %	ID ≥3%	533	0.059	0.220	0.490; -0.372	0.79	98.90
	SI	383	-0.153	0.087	0.018; -0.325	0.08	15.50
	LC	282	0.364	0.295	0.942; -0.214	0.22	99.47
	E	351	-0.322	0.205	0.079; -0.725	0.12	82.67
	G	314	0.246	0.238	0.713; -0.221	0.30	99.09
	Overall	823	0.335	0.185	0.698; -0.028	0.07	54.51
	ID <3%	324	-0.510	1.038	1.525; -2.546	0.62	77.74
	ID ≥3%	499	0.260	0.143	0.542; -0.028	0.07	31.22
L*	SI	607	-0.105	0.436	0.748; -0.959	0.81	48
	LC	216	0.479	0.201	0.084; 0.875	0.02	67.21
	E	543	0.206	0.464	1.116; -0.702	0.66	70.76
	G	280	0.127	0.109	0.340; -0.086	0.24	12.85
	Overall	791	0.311	0.187	0.678; -0.055	0.09	93.80
	ID <3%	324	1.142	0.543	0.076; 2.207	0.04	94.15
	ID ≥3%	467	-0.232	0.094	-0.047; -0.416	0.01	50.06
	SI	575	0.112	0.300	0.701; -0.477	0.71	82.76
a*	LC	216	0.567	0.277	0.024; 1.110	0.04	96.91
	E	543	0.739	0.423	1.569; -0.089	0.08	93.27
	G	248	-0.300	0.090	-0.122; -0.479	0.00	45.82
	Overall	791	-0.206	0.111	-0.078; -0.513	0.01	86.80
	ID <3%	324	-0.565	0.294	0.010; -1.141	0.05	90.53
	ID ≥3%	467	-0.117	0.117	0.112; -0.346	0.32	81.49
	SI	575	-0.105	0.104	0.099; -0.309	0.312	45.85
	LC	216	-0.511	0.181	-0.156; -0.866	0.00	92.23
b*	E	543	-0.500	0.227	-0.054; -0.946	0.27	92.49
	G	248	-0.174	0.107	0.035; -0.384	0.10	57.86

n – number of animals; pH<sub>i</sub> – initial pH; pH<sub>u</sub> – ultimate pH; DL – drip loss; L\* – lightness; a\* – redness; b\* – yellowness; ID <3% – inulin dose in diet below 3%; ID ≥3% – inulin dose in diet equal or higher than 3%; SI – standard inulin; LC – long chain inulin; E – electrical stunning; G – carbon dioxide stunning; SE – standard error; 95%CI – confidence interval; I<sup>2</sup> – percentile of total variation due to heterogeneity

although with high heterogeneity between studies. The stunning had the effect only on redness of pork. The meta-analysis shown that the loins of pigs fed with inulin and stunned with CO<sub>2</sub> had significantly lower a\* values in comparison with those from control group with moderate heterogeneity between studies (I<sup>2</sup> = 45.82%).

## Discussion

Over the past decade, feeding strategies of pigs focused on in-feed antibiotic alternatives that exhibit potential to enhance growth potential and immune response of pigs. As an alternative, supplementing prebiotics gained a great interest in recent years.

Inulin supplementation in pigs has been shown to improve growth performance (Rosenvold et al., 2001a; Hansen et al., 2002; Wellock et al., 2008; Ponnampalam et al., 2009; Grela et al., 2013; Sobolewska and Grela, 2014; Samolińska and Grela, 2017; Sobol et al., 2018; Grela et al., 2021). Jayasooriya et al. (2009) found that inulin supplementation at 5% of the diet increased average daily gain (ADG) by 6.2% in boars and 4.2% in gilts, compared to the control group. Furthermore, there was a 10.5 and 16.5% increase in ADG of boars and gilts, when the diets were supplemented with both organic Fe (at 500 mg/kg) and inulin. Grela et al. (2013) reported increased ADG and ADFI in growing-finishing pigs fed diet with 3% inulin. Samolińska and Grela (2017) reported, that inclusion of 1, 2 and 3% inulin resulted in dose dependent increase in ADG. Samolińska et al. (2018) found that supplementation with 2% long-chain inulin increased the ADG at the finishing stage of fattening. Wang et al. (2020) reported that dietary inulin supplementation had no significant influence on the growth performance in weaned pigs. But found that inulin supplementation with 2.5% increased the ADG by 20.1 %, as compared with the control group. Dunshea et al. (2024) reported that inulin supplementation at 5% of the diet increased ADG by 6.2% compared to the control group. Other studies have shown no effect of inulin supplementation on performance of the weaned (Mikkelsen et al., 2003; Pierce et al., 2005; Yasuda et al., 2009; Ivarson et al., 2012; San Andres et al., 2019; Yang et al., 2023) and growing-finishing pigs (Øverland et al., 2011; Vhile et al., 2012; Aluwé et al., 2017; Deng et al., 2017; Samolińska et al., 2019; McCormack et al., 2019; Hu et al., 2020).

In this research, meta-analysis indicated that inulin supplementation significantly improved ADG (0.017 kg/day) in growing-finishing pigs. However, there was high heterogeneity ( $I^2 = 92.80\%$ ) across all studies, indicating that other factors may have the impact on ADG in growing-finishing pigs (Table 3).

The link between inulin supplementation and growth performance of pigs is still unclear, however is attributed by researchers to intestinal health and gut microbiome (Gardiner et al., 2020; Han et al., 2022; Liu et al., 2023). Inulin may exert the effects on performance traits through several potential mechanisms including proliferation of beneficial microbes and their metabolites with biological activities for the host, improvement of intestinal morphology, increase in the absorption of available nutrients and minerals, modulation of the expression of inflammatory cytokines or upregulated expression of growth-related genes (Yasuda et al., 2006; Wang et al., 2020).

In monogastric animals, inulin is resistant to hydrolysis by digestive enzymes due to  $\beta$ -linkages between their monomers but can be fermented by several bacterial genera, such as *Lactobacillus*, *Bifidobacterium*, and *Bacteroides* in the large intestine, mainly in the caecum (Yasuda et al., 2007; Patterson et al., 2010). However, Böhmer et al. (2005) and Loh et al. (2006) found that 20–50% of dietary inulin, was fermented in the porcine jejunum by the resident microflora.

Gut microbiomes and short-chain fatty acids (SCFAs) exert positive effects on growth performance of pigs (Bergamaschi et al., 2020; Gardiner et al., 2020; Han et al., 2022).

Overall, several bacterial taxa have been shown as associated with growth of pigs, although data are conflicting in some references. Tang et al. (2020) reported that *Alloprevotella* and *Rumiococcaceae* were positively correlated with body weight and average daily gain of pigs while the *Prevotellaceae* genera with backfat thickness and intramuscular fat content. In a 16S rRNA gene sequencing study, Bergamaschi et al. (2020) identified operational taxonomic units (OTUs) of *Clostridium*, *Prevotella*, *Lactobacillus* and *Eubacterium* as having association with average daily gain and fat content in crossbreed pigs. Mach et al. (2015) and Oh et al. (2020) also found, that genera *Lactobacillus* and *Prevotella* exhibited positive associations with body weight and ADG whereas Yang et al. (2021) detected associations of these traits with *Lactobacillus*, *Bacterioides* and *Prevotellaceae*. Recently, Lan et al. (2023), based on data of the 16s ribosomal RNA gene and metagenomic analysis detected that carbohydrate-decomposing bacteria of the families *Streptococcaceae*, *Lactobacillaceae* and *Prevotellaceae* were positively related to finishing weight of pigs whereas taxa associated with inflammation exhibited opposite effects. Similarly, Lee et al. (2023) showed, higher abundances of *Bifidobacterium* and *Lactobacillus* in faces of pigs with higher growth rate.

Inulin fermentation by the endogenous microbiota promotes the growth of *Lactobacilli* and *Bifidobacteria* which in turn produce both, SCFAs, mainly acetate, propionate, and butyrate, and organic acids (Flickinger et al., 2003). SCFAs have different modes of action such as stimulation the growth of health-promoting bacteria such as *Bifidobacteria* and *Lactobacilli* (Tako et al., 2008), facilitation the absorption of minerals (Topping and Clifton, 2001), decrease in the pH of the large intestine, inhibition the growth of pathogenic microorganisms (Ma et al., 2022) or regulation of lipid

and glucose metabolism (Zhou et al., 2021). Furthermore, dietary inulin stimulates growth of other SCFAs promoting bacteria, such as *Prevotella*, *Bacterioides*, *Veillonella*, and *Faecalibacterium* (McCormack et al., 2019; Wu et al., 2020) as well as lowers the relative abundances of potentially pathogenic bacteria as *Escherichia*, *Clostridium* spp. and the members of *Enterobacteraceae* (Patterson et al., 2010). Nonetheless, the effects of inulin on gut microbiota and SCFAs concentration are often inconsistent. Eberhard et al. (2007) reported that weaned pigs fed with 3% inulin showed lower concentrations of caecal acetate and total SCFA while inulin supplementation had no effect on abundance of *Bifidobacterium*, *Lactobacillus*, *Enterococcus* and *Enterobacterium* genera. Patterson et al. (2010) showed that inclusion of 4% of inulin increased the abundance of *Bifidobacteria* and *Lactobacilli* in ileum and cecum of weaned pigs. Ivarson et al. (2012) showed that inclusion of 8% inulin in the fed of weaned pigs increased abundance of *Lactobacilli*, *Bacteroides* and *Prevotella*. Mair et al. (2010) found that supplementation with 0.4% inulin had no effect on abundance of *Bifidobacterium*, *Lactobacillus* but reduced acetic acid and total SCFA in colon of weaned pigs. In contrast, He et al. (2021) reported that supplementation with 0.5% inulin significantly increased abundance of *Lactobacillus* spp. and decreased the abundance of *Enterobacteraceae* in ileal samples of weaned pigs. Lynch et al. (2007) found that supplementation of finishing pigs with 1.25% inulin increased caecal *Bifidobacteria* and reduced *Enterobacteriaceae* but did not impact on SCFA concentration. Varley et al. (2010) reported that inulin supplementation with 2% decreased *Enterobacteriaceae* populations in the proximal colon of finishing pigs but did not affect populations of *Bifidobacteria* and *Lactobacilli*. Nonetheless, increased total SCFA and butyric acid in caecum and proximal colon of inulin fed pigs. Sobolewska and Grela (2015) found that supplementation with 4% of Jerusalem artichoke increased propionic, isobutyric, butyric and isovaleric acids in caecum of growing-finishing pigs while inclusion of 4% chicory root powder increased acetic, propionic and butyric acids in colon digesta. Overall, in comparison with weaners, growing-finishing pigs have larger, longer and more mature digestive system which makes them more capable to fibre utilisation (Li et al., 2021). Nonetheless, decreased SCFAs or no effect of dietary inulin on SCFAs concentration may result from its increased absorption in colonocytes. Hu et al. (2020) reported that supplementation with 2% inulin induced the expression of the SCFAs

transporters SLC5A8 and SLC16A1 in colonocytes of growing pigs. Furthermore, response differences of gut microbiota to inulin supplementation may be dependent on the initial *Bifidobacteria* level or *Bacteroides/Bifidobacterium* ratio (Yin et al., 2023). Thus, individual variability of gut microbiota of the host may also be potential reason of response variability to inulin (Ojima et al., 2022) and therefore, different effects on growth of pigs. The effects of inulin on performance traits may also be depend on dose and DP of inulin.

Reference data shows that pigs respond better in performance traits at higher inulin doses (Rosenvold et al., 2001a; Hansen et al., 2002; Jayasooriya et al., 2009; Ponnampalam et al., 2009; Grela et al., 2013; Samolińska and Grela, 2017; Sobol et al., 2018). Metzler-Zebeli et al. (2017) reported that 3–5% inulin in diet is recommended as minimal dose to modulate physiological and microbial parameters in the gastrointestinal tract of pigs. Nonetheless, these authors using meta-regression analysis, showed negative relationship between dietary inulin concentration and colonic bifidobacteria while inulin concentration had no effect on SCFA concentration.

In this research, meta-analysis indicated, that inulin supplementation in growing-finishing pigs significantly ( $P \leq 0.01$ ) increased ADG in both dose-dependent subgroups. However, these dose-dependent effects of inulin supplementation differed in narrow range of the effect size and 95% CI. However, there was high heterogeneity ( $I^2 = 90.18\%$  and  $73.45\%$  respectively) across all studies, indicating that other factors may have impact on ADG (Table 3).

The chain length (DP) of inulin may also be potential reason of variability in performance traits of pigs. Inulin with higher chain length was found to have a more beneficial effects on ADG than short chain inulin (Samolińska and Grela, 2017; Samolińska et al., 2018; Grela et al., 2021). Samolińska and Grela (2017) found that inclusion of 2 or 3% long-chain inulin in fed of growing-finishing pigs exerted more pronounced effects on ADG than application in similar doses of standard inulin with average DP of 10. In later studies, Samolińska et al. (2018) indicated that supplementation with 2% long-chain inulin significantly improved the ADG and FCR of the grower-finisher pigs. The DP of inulin affects the end products of gut microbial fermentation. Short-chain inulin exhibits more rapid fermentation than long-chain inulin (Stewart et al., 2008). Yasuda et al. (2009) reported that short-chain inulin can be fermented

to some extent in the jejunum and ileum where the resistant microbiota shift to more aerotolerant species such as *Lactobacilli*. Patterson et al. (2010) found that long-chain inulin was fermented in distal ileum or the cecum where the bacterial populations shift to more anaerobic species such as *Bifidobacteria* and *Bacteroides*.

In this study, meta-analysis indicated, that supplementation both short and long-chain inulin significantly increased ADG in growing-finishing pigs. Nonetheless, the larger effect detected for long-chain inulin (Table 3).

Dietary inulin in pig diet can positively impact feed intake (Hansen et al., 2002; Yasuda et al., 2009; Grela et al., 2013; 2014; Wang et al., 2020) potentially by modifying the gastrointestinal microbiome, enhancing nutrition absorption and production of SCFAs (Yasuda et al., 2009; Grela et al., 2014; Wang et al., 2020; He et al., 2021). Nonetheless, the effects of inulin supplementation on ADFI are not consistent between studies. Pigs in some experiments have reduced ADFI (Rosenvold et al., 2001a,b; Sobol et al., 2018) whereas ADFI remained constant in others (Vhile et al., 2012; Deng et al., 2017; Samolińska et al., 2018; McCormack et al., 2019; Yang et al., 2023).

In this study, meta-analysis indicated that inulin supplementation significantly decreased ADFI (by 0.035 kg) in weaned pigs. However,  $I^2$  statistics detected that there was substantial heterogeneity ( $I^2 = 91.71\%$ ) between studies. Inulin dose and the chain length had no effect on ADFI. Furthermore, none of the factors employed to stratify the studies showed differences in FCR between inulin fed and control pigs (Table 3).

The adverse effects of inulin on ADFI may be controlled by various mechanisms. As previously noted, weaned pigs have immature digestive system that makes them less capable to fibre utilisation. In weaned pigs, dietary inulin may tend to decrease feed intake compared to control diet due to increased gut fill and earlier satiety (Brambillasca et al., 2015). Metzler-Zebeli et al. (2017) reported that increase in dietary levels of inulin was negatively correlated with coefficient of ileal apparent digestibility of dry matter. Additionally, effects of inulin on appetite may also be linked with concentration of ileal propionic acid. Propionic acid is a weak organic acid that can easily cross the intestinal barrier and the blood-brain barrier to reach the brain (MacFabe et al., 2007) where it may exert limited appetite-suppressing effect.

In Europe, pork-oriented consumers are not consistent in their preferences towards meat.

Nonetheless, in most countries, they prefer pork chains that deliver meat of high quality and health (Lin-Schilstra et al., 2022). Additionally, many of them, favour pork produced without antibiotics (Paudel et al., 2022). Pork labelled as ‘raised without antibiotics’ is perceived by consumers as having better quality and producing with higher welfare standards (Bradford et al., 2021). Fresh meat quality encompasses a range of attributes that determine its usefulness to the consumer (Joo et al., 2013). Some of them, as fat content, colour or water-holding capacity (WHC) determine quality at the moment of purchase, others such as tenderness or juiciness at the moment of consumption (Grunert et al., 2004). Meat quality is influenced by various pre- and post-slaughter factors (Warner et al., 2010). Nutrition plays a critical role in meat quality development (Apple, 2013). Reference data shows that dietary fibre in fed of pigs may modify meat quality (Li et al., 2015; Cho et al., 2015; Han et al., 2020). Dietary inulin supplementation in pig fed positively influences on meat quality. Research indicates that inulin enhances colour through increase in redness (Ponnampalam et al., 2009; Przybylski et al., 2019) and improvement in antioxidant stability (Ponnampalam et al., 2009; Grela et al., 2021). Additionally, inulin contributes to better water-holding capacity (Rosenvold et al., 2001a; 2002; 2003) and reduced share force (Sobolewska and Grela, 2014; Grela et al., 2021). Nonetheless, the effects of inulin supplementation on meat quality are not consistent between studies. In some experiments, pigs supplemented with inulin have reduced redness (Sobolewska and Grela, 2014; Grela et al., 2021), water-holding capacity (Aluwé et al., 2013) or tenderness (Rosenvold et al., 2001a; 2001b) others showed no effect of inulin on pork quality traits (Hansen et al., 2008; Wang et al., 2019; Dunshea et al., 2024). Dietary inulin may exert effects on meat quality through several potential mechanisms. These include regulation of skeletal muscle metabolism, transformation of muscle fibre type or intramuscular fat deposition (Han et al., 2022; Wen et al., 2024). Overall, inulin modulates microbial composition and some metabolites including SCFAs that regulate glucose metabolism (Yan et al., 2023). In skeletal muscle SCFAs improve glucose uptake through increased expression of glucose transporter type 4 (GLUT4) induced by AMP kinase (AMPK) (Han et al., 2022). Furthermore, AMPK activation inhibits glycogen synthesis by suppressing of glycogen synthase (GS) to maintain the energy balance in muscle. Thus, the state of AMPK prior to slaughter may modulate *in vivo* glycogen stores in skeletal muscle and

post-mortem glycolysis and thereby meat quality (Shen et al., 2006). The greater glycolytic potential (GP) have muscles in the absence of AMPK activation (Scheffler and Gerrard, 2007). In mice, Miao et al. (2021) reported that supplementation with inulin (3.33 g/kg/day) for 4 weeks significantly increased GLUT4 expression. Additionally, inulin has been linked to improved metabolic markers related to postmortem glycolysis, aldolase (ALD), pyruvate kinase (PK) and phosphoglucose isomerase (PGI) (Przybylski et al., 2019). PGI catalyses the conversion the conversion of glucose 6-phosphate to fructose 6-phosphate while ALD catalyses fructose 1,6 biphosphate to glyceraldehyde 3-phosphate at the initial stage of glycogenolysis. PK catalyses conversion of phosphoenolpyruvate to pyruvate at the final stage of glycogenolysis. The amount of initial glycogen content together with the activity of glycolytic enzymes are key biochemical factors responsible for post-mortem glycolysis and pH development (Scheffler and Gerrard, 2007). Przybylski et al. (2019) reported that growing-finishing pigs fed diet with inulin (7% of daily feed intake) displayed significantly higher levels of PK/PGI and ADL than those from control group. Furthermore, dietary fibre through modulation of gut microbiome composition and microbial metabolites can transform muscle fibre profile (Li et al., 2015; Han et al., 2020). Overall, muscle fibre is divided into four types including slow-oxidative or type I, oxido-glycolytic or type IIA and fast-glycolytic IIX and IIB, which are encoded by myosin heavy chain (MyHC) isoform genes: I, IIA, IIX, and IIB, respectively (Lefaucheur et al., 2002). The difference in muscle fibre composition affects the meat quality. The fibre type IIB contains higher amounts of glycogen and have higher glycolytic enzymes activity than fibre type I. Consequently, the higher proportion of glycolytic fibres is associated with an accelerated pH decline after the slaughter, decreased water-holding capacity and paler colour (Choe et al., 2008; Joo et al., 2013). Thus, the increase in the proportion of slow-twitch or oxidative muscle fibres contributes to better meat quality. Han et al. (2020) reported that Eurlian pigs fed diet with 7% wheat bran exhibited significantly lower expression of MyHC IIB and higher expression of MyHC I than those fed with control, 14 and 21% wheat bran. Liu et al. (2024) showed that increase in soluble dietary fibre to insoluble dietary fibre ratio (from 0.15 to 0.25) decreased fast-twitch myosin heavy chain (MyHC IIB) and increased slow-twitch myosin heavy chain (MyHC I) protein expression. The mechanism by which dietary

fibre may transform muscle fibre profile is still unknown. According to Zhang et al. (2019) alterations in SCFAs can inhibit deacetylase enzyme activity, promote peroxisome proliferator activated receptor gamma coactivator-1 alpha (PGC-1 $\alpha$ ) and further increase of MyHC I expression. The effects of inulin on muscle fibre profile are relatively little known. Nonetheless, Wang et al. (2019) reported that supplementation with inulin (0.5%) significantly elevated expression level of MyHC IIB.

Research indicates that high doses of inulin may decrease glycogen reserves in skeletal muscles before the slaughter (Rosenvold et al., 2001b; 2003). Rosenvold et al. (2001b) reported that pigs fed with inulin (25%) for three weeks before the slaughter displayed significantly lower levels of glycogen than those from control group. Nonetheless, they did not show the impact of inulin on ultimate pH. Hansen et al. (2008) showed that pigs supplemented with 5% inulin exhibited lower levels of glycogen at 45 min and 24 h after the slaughter but did not significantly differ from the control group. Additionally, pH at 45 min. and 24 h after the slaughter did not significantly differ between feeding treatments. Przybylski et al. (2019) reported that supplementation with 7% of inulin both for 40 and 70 days had no effect on glycolytic potential (GP) and glucose content at 45 min after the slaughter but pigs fed inulin for 40 days displayed significantly higher levels of lactic acid. Nonetheless, these authors found that only supplementation with 7% of inulin both for 70 days significantly improved ultimate pH.

The meta-analysis demonstrated no effect of inulin supplementation both on pH<sub>1</sub> and pH<sub>u</sub>. Furthermore, none of the factors employed to stratify the studies showed differences in pH<sub>1</sub> and pH<sub>u</sub> between inulin feed and control pigs (Table 4).

Drip loss and colour are the most important meat quality traits strongly associated with consumer habits and willingness to pork purchase (Henchion et al., 2014). The water release from fresh meat depends on various factors including breed, rearing condition with feeding pattern, transport, stunning and post-slaughter treatments e.g., chilling of carcasses (Hughes et al., 2014). All of these factors in post-mortem various extent affect biochemical and structural events, such as the rate and extent of pH decline post-mortem, myofibrillar shrinkage and contraction, permeability of cell membranes to water, and the development of drip channels and extracellular space, that are responsible for water release from meat (Schafer et al., 2002). Nutrition has rather lower effect on drip loss than genetics and pre- and post-slaughter

management, but there is evidence that dietary modifications may enhance the water release from meat (Apple, 2007). Research indicates that high fibre diets may enhance meat quality by improving water-holding capacity (Li et al., 2015; Cho et al., 2015). The high doses of inulin in diet of pigs may enhance drip loss through combined effects on glycogen synthesis in muscles and pattern of post-mortem glycolysis linked with the rate and range of pH decline. Rosenfold et al. (2002; 2003) reported that inulin supplementation at 25% of the diet improved drip loss. Nonetheless, Sobolewska and Grela (2014) found that loins of pigs supplemented with 2% of inulin exhibited better water-holding capacity than those from control group. In contrast Aluwé et al. (2013) reported that loins of pigs that were fed with 7% of inulin, despite of higher ultimate pH in comparison with those from control group (5.6 vs. 5.4), had significantly higher drip loss. Others reported no effect of inulin supplementation on drip loss (Hansen et al., 2008; Ponnampalam et al., 2009; Dunshea et al., 2024; Wang et al., 2019; Grela et al., 2021). Similarly, Przybylski et al. (2019) reported that supplementation with 7% of inulin, both for 40 and 70 days, had no effect on drip loss, but loins of pigs fed with inulin for 40 days displayed higher by 1.3 p.p. drip loss in comparison to those fed for 70 days and control pigs. However, this insignificance may be due to low statistical power (5 animals in each group) rather than an ineffective intervention.

In this research, the meta-analysis demonstrated no effect of inulin supplementation on drip loss. Furthermore, none of the factors employed to stratify the studies showed differences in drip loss between inulin feed and control pigs (Table 4).

The lightness of fresh meat depends on the concentration of myoglobin and muscle microstructure that influences light scattering whereas redness and yellowness are linked to myoglobin concentration and the chemical state of myoglobin (Purslow et al., 2021). These biochemical and physiological properties of meat are related to complex of intrinsic (e.g., breed, muscle type, diet) and extrinsic (pre-slaughter handling, transport, stunning, carcass chilling) factors that occur along the production chain (Mancini and Hunt, 2005). Nutrition has limited effect on meat colour (Gagaoua et al., 2023). However, dietary supplementation with magnesium or vitamin D3 has been shown to improve pork colour (Wilborn et al., 2004; Apple et al., 2007;). Several meta-analyses also reported nutritional modifications of pork colour. Trefan et al. (2010) showed a positive effect of dietary vitamin E supplementa-

tion on pork redness ( $a^*$  value). Wang et al. (2021) reported that polyunsaturated fatty acids (PUFAs) supplementation decreased the lightness ( $L^*$ ) of pork loins. Reference data shows that dietary inulin in fed of pigs has rather limited effect on pork colour. The incorporation of high doses of inulin in fed of pigs has been shown to reduce the lightness of pork (Rosenfold et al., 2002). Ponnampalam et al. (2009) found that supplementation with 5% of inulin increased redness of pork loins. The mechanism of inulin action on pork colour is not fully clear. Potentially, dietary inulin influences pork colour by altering the biochemical and physiological properties of meat. However, Sobolewska and Grela (2014) and Grela et al. (2021) reported that supplementation with 2% of inulin significantly reduced redness and increased yellowness of pork loins. These alterations in pork colour may be potentially linked with combined effects of dietary inulin on antioxidant stability and proportion of muscle fibre type. Grela et al. (2021) reported that loins of pigs fed a diet supplemented with 2% of inulin displayed higher oxidative stability (lower values of TBARS – 2-thio-barbituric acid reactive substances) than those from control group. The authors explain that this effect may be linked with the lower content of myoglobin which shows pro-oxidative effects due to presence of Fe. The concentration of myoglobin varies depending on muscle fibre type. Muscle fibres of type I and type IIb possesses higher myoglobin levels than type IIb muscle fibres (Lefaucheur, 2010). Wang et al. (2019) reported that supplementation with inulin (0.5%) significantly elevated expression level of MyHC IIB. Nonetheless, these authors found no effect of dietary inulin on pork colour. Similarly, other researchers (Hansen et al., 2008; Jayasooriya et al., 2009; Aluwé et al., 2013; Dunshea et al., 2024) reported no effect of inulin supplementation on pork colour.

In this research, the meta-analysis of all available results revealed significantly higher yellowness ( $b^*$ ) of loins from inulin supplemented pigs and no significant differences in lightness ( $L^*$ ) or redness ( $a^*$ ) between inulin feed and control pigs. However, there was high heterogeneity ( $I^2 = 86.80\%$ ) across all studies, indicating that other factors may have the influence on pork colour. In sub-groups, the application of LC inulin significantly increased the lightness ( $L^*$ ) and redness ( $a^*$ ) and decreased the yellowness ( $b^*$ ) of meat, but with high heterogeneity between studies. Inulin dose, modified only redness and yellowness of pork. The application of inulin at lower than 3% dose in diet of pigs resulted in significant increase in  $a^*$  and decrease in  $b^*$

value. At higher doses, equal or above 3%, inulin significantly decreased  $a^*$  with no effect on  $b^*$ . Stunning method modified only redness of pork. The loins of pigs fed with inulin and stunned with CO<sub>2</sub> exhibited significantly lower  $a^*$  values in comparison with those from control group. The I<sup>2</sup> statistic in this sub-group (45.82%), however, shows moderate heterogeneity between studies (Table 4).

## Conclusions

The findings of this meta-analysis suggest that inulin supplementation may exert positive effects on average daily gain (ADG), although the magnitude of these effects may depend on the production stage or degree of polymerisation of inulin. The application of inulin significantly improved ADG only in growing-finishing pigs, although the largest effect detected with application of long-chain inulin. Inulin dose (<3% or ≥3%) significantly improved modified ADG of grower-finisher pigs but in similar range of the effect size. However, supplementation of inulin in feed of pigs may result in increase of average daily feed intake. Nonetheless, this trend has been detected only in weaning pigs. Dietary inulin did not have the effect on initial and ultimate pH and drip loss but significantly modified the colour of pork under the several study factors. A trend to increase in redness and decrease in yellowness was detected in loins of pigs fed with lower (<3%) doses of inulin, nonetheless the application of long-chain inulin may result in increase of lightness of meat.

## Acknowledgements

The manuscript was realized under the COOPERATION measure of the Rural Development Programme for 2014–2024 by the Agency for Restructuring and Modernisation of Agriculture (00119.DDD.6509.00063.2022.07).

## Conflict of interest

The Authors declare that there is no conflict of interest.

## References

- Aluwé M., Langendries K.C.M., Beakert K.M., Tuytens F.A.M., De Brabander D.L., De Smet S., Millet S., 2013. Effect of surgical castration, immunocastration and chicory-diet on the meat quality and palatability of boars. *Meat Sci.* 94, 402–407, <https://doi.org/10.1016/j.meatsci.2013.02.015>
- Aluwé M., Heyrman E., Theis S., Sieland C., Thurman K., Millet S., 2017. Chicory fructans in pig diet reduce skatole in back fat of entire male pigs. *Res. Vet. Sci.* 115, 340–344, <https://doi.org/10.1016/j.rvsc.2017.06.016>
- Apolinario A.C., de Lima Damasceno B.P.G., de Macedo Beltrao N.E., Pessoa A., Converti A., da Silva J.A., 2014. Inulin-type fructans: a review on different aspects of biochemical and pharmaceutical technology. *Carbohydr. Polym.* 101, 368–378, <https://doi.org/10.1016/j.carbpol.2013.09.081>
- Apple J.K., 2007. Effects of nutritional modifications on the water-holding capacity of fresh pork: A review. *J. Anim. Breed. Genet.* 124, 43–58, <https://doi.org/10.1111/j.1439-0388.2007.00686.x>
- Apple J.K., 2013. Swine nutrition and pork quality. In: L. Chiba (Editor). *Nutrition for Successful and Sustainable Swine Nutrition*. Wiley-Blackwell, Ames, Iowa, USA. 413–437, <https://doi.org/10.1002/9781118491454.ch17>
- Apple J.K., Roberts W.J., Maxwell C.V., Rakes L.K., Friesen K.G., Fakler T.M., 2007. Influence of dietary inclusion level of manganese on pork quality during retail display. *Meat Sci.* 75, 640–647, <https://doi.org/10.1016/j.meatsci.2006.10.006>
- Bakbergenuly I., Hoaglin D.C., Kulinskaya E., 2020. Estimation in meta-analyses of mean difference and standardized mean difference. *Stat. Med.* 39, 171–191, <https://doi.org/10.1002/sim.8422>
- Barrett J.R., Innes G.K., Johnson K.A., Lhermie G., Ivanek R., Greiner Safi A., Lansing D., 2021. Consumer perceptions of antimicrobial use in animal husbandry: A scoping review. *PLoS ONE.* 16, e0261010, <https://doi.org/10.1371/journal.pone.0261010>
- Bergamaschi M., Maltecca C., Schillebeeckx C., McNulty N.P., Schwab C., Shull C., Fix J., Tiezzi F., 2020. Heritability and genome-wide association of swine gut microbiome features with growth and fatness parameters. *Sci. Rep.* 10, 10134, <https://doi.org/10.1038/s41598-020-66791-3>
- Birmani M.W., Nawab A., Ghani M.W., Li G., Xiao M., An L.A., 2019. Review: Role of inulin in animal nutrition. *J. Food Technol. Res.* 6, 18–27, <https://doi.org/10.18488/journal.58.2019.61.18.27>
- Borenstein M., Hedges L.V., Higgins J.P.T., Rothstein H.R., 2009. *Introduction to meta-analysis*. Wiley, Chichester, UK <https://doi.org/10.1002/9780470743386>
- Böhmer B.M., Branner G.R., Roth-Maier D.A., 2005. Precaecal and faecal digestibility of inulin (DP 10-12) or an inulin/*Enterococcus faecium* mix and effects on nutrient digestibility and microbial gut flora. *J. Anim. Physiol. Anim. Nutr. (Berl.)* 89, 388–396, <https://doi.org/10.1111/j.1439-0396.2005.00530.x>
- Bradford H., McKernan C., Elliott C., Dean M., 2021. Consumers' perceptions and willingness to purchase pork labelled 'raised without antibiotics'. *Appetite* 171, 105900, <https://doi.org/10.1016/j.appet.2021.105900>
- Brambillasca S., Zunino P., Cajarville C., 2015. Addition of inulin, alfalfa and citruspulp in diets for piglets: Influence on nutritional and faecal parameters, intestinal organs, and colonic fermentation and bacterial populations. *Livestock Sci.* 178, 243–250, <https://doi.org/10.1016/j.livsci.2015.06.003>
- Chen T.T., Chen D.W., Tian G., Zheng P., Mao X.B., Yu J., He J., Huang Z.Q., Luo Y.H., Luo J.Q., Yu B., 2020. Effects of soluble and insoluble dietary fiber supplementation on growth performance, nutrient digestibility, intestinal microbe and barrier function in weaning piglet. *Anim. Feed Sci. Technol.* 260, 114335, <https://doi.org/10.1016/j.anifeedsci.2019.114335>
- Cho J.H., Lee S.I., Kim I.H., 2015. Effects of different levels of fibre and benzoic acid on growth performance, nutrient digestibility, reduction of noxious gases, serum metabolites and meat quality in finishing pigs. *J. Appl. Anim. Res.* 43, 336–344, <https://doi.org/10.1080/09712119.2014.978772>

- Choe J.H., Choi Y.M., Lee S.H., Shin H.G., Ryu Y.C., Hong K.C., Kim B.C., 2008. The relationship between glycogen, lactate content and muscle fiber type composition, and their influence on postmortem glycolytic rate and pork quality. *Meat Sci.* 80, 355–362, <https://doi.org/10.1016/j.meatsci.2007.12.019>
- Deng Y., Liu Y., Zhang Y., Wang Y., Liang J.B., Tufarelli V., Laudadio V., Liao X., 2017. Efficacy and role of inulin in mitigation of enteric sulfur-containing odor in pigs. *J. Sci. Food Agric.* 97, 2382–2391, <https://doi.org/10.1002/jsfa.8050>
- Denver S., Jensen J.D., Christensen T., 2021. Consumer preferences for reduced antibiotic use in Danish pig production. *Prev. Vet. Med.* 189, 105310, <https://doi.org/10.1016/j.prevet-med.2021.105310>
- Dunshea F.R., Pluske J.R., Ponnampalam E.N., 2024. Dietary iron or inulin supplementation alters iron status, growth performance, intramuscular fat and meat quality in finisher pigs. *Meat Sci.* 213, 109496, <https://doi.org/10.1016/j.meatsci.2024.109496>
- Eberhard M., Hennig U., Kuhla S., Brunner R.M., Kleessen B., Metzges C.C., 2007. Effect of inulin supplementation on selected gastric, duodenal, and caecal microbiota and short chain fatty acid pattern in growing piglets. *Arch. Anim. Nutr.* 61, 235–246, <https://doi.org/10.1080/17450390701431631>
- Flickinger E.A., Van Loo J., Fahey G.C. Jr., 2003. Nutritional responses to the presence of inulin and oligofructose in the diets of domesticated animals: A review. *Crit. Rev. Food Sci. Nutr.* 43, 19–60, <https://doi.org/10.1080/10408690390826446>
- Gagaoua M., Suman S.P., Purslow P.P., Lebret B., 2023. The color of fresh pork: Consumers expectations, underlying farm-to-fork factors, myoglobin chemistry and contribution of proteomics to decipher the biochemical mechanisms. *Meat Sci.* 206, 109340, <https://doi.org/10.1016/j.meatsci.2023.109340>
- Gardiner G.E., Metzler-Zebeli B.U., Lawlor P.G., 2020. Impact of intestinal microbiota on growth and feed efficiency in pigs: a review. *Microorganisms* 8, 1886, <https://doi.org/10.3390/microorganisms8121886>
- Gibson G.R., Scott K.P., Rastall R.A. et al., 2010. Dietary prebiotics: Current status and new definition. *Food Sci. Technol. Bull. Funct. Foods* 7, 1–19, <https://doi.org/10.1616/1476-2137.15880>
- Grela E.R., Pietrzak K., Sobolewska S., Witkowski P., 2013. Effect of inulin and garlic supplementation in pig diets. *Ann Anim Sci.* 13, 63–71, <https://doi.org/10.2478/v10220-012-0059-6>
- Grela E.R., Sobolewska S., Kowalczyk-Vasilev E., Krasucki W., 2014. Effect of dietary inulin source on piglet performance, immunoglobulin concentration, and plasma lipid profile. *Bull. Vet. Inst. Pulawy* 58, 453–458, <https://doi.org/10.2478/bvip-2014-0069>
- Grela E.R., Swiatkiewicz M., Florek M., Bakowski M., Skiba G., 2021. Effect of inulin source and a probiotic supplement in pig diets on carcass traits, meat quality and fatty acid composition in finishing pigs. *Animals* 11, 2438, <https://doi.org/10.3390/ani11082438>
- Grunert K.G., Bredahl L., Brunsø K., 2004. Consumer perception of meat quality and implications for product development in the meat sector - A review. *Meat Sci.* 66, 259–272, [https://doi.org/10.1016/S0309-1740\(03\)00130-X](https://doi.org/10.1016/S0309-1740(03)00130-X)
- Grunert K.G., Sonntag W.I., Glanz-Chanos V., Forum S., 2018. Consumer interest in environmental impact, safety, health and animal welfare aspects of modern pig production: Results of a cross-national choice experiment. *Meat Sci.* 137, 123–129, <https://doi.org/10.1016/j.meatsci.2017.11.022>
- Halas D., Hansen C.F., Hampson D.J., Mullan B.P., Wilson R.H., Pluske J.R., 2009. Effect of dietary supplementation with inulin and/or benzoic acid on the incidence and severity of post-weaning diarrhoea in weaner pigs after experimental challenge with enterotoxigenic *Escherichia coli*. *Arch. Anim. Nutr.* 63(4), 267–280, <https://doi.org/10.1080/17450390903202414>
- Han P., Li P., Zhou W., et al., 2020. Effects of various levels of dietary fiber on carcass traits, meat quality and myosin heavy chain I, IIa, IIx and IIb expression in muscles in erhualian and large white pigs. *Meat Sci.* 169, 108160, <https://doi.org/10.1016/j.meatsci.2020.108160>
- Han Q., Huang X., Yan F., Yin J., Xiao Y., 2022. The role of gut microbiota in the skeletal muscle development and fat deposition in pigs. *Antibiotics* 11, 793, <https://doi.org/10.3390/antibiotics11060793>
- Hansen L.L., Agerhem H., Rosenvold K., Jensen M.T., 2002. Effect of Brussels sprouts and inulin/rape seed cake on the sensory profile of pork *M. longissimus dorsi*. *Meat Sci.* 61, 441–448, [https://doi.org/10.1016/S0309-1740\(01\)00218-2](https://doi.org/10.1016/S0309-1740(01)00218-2)
- Hansen L.L., Stolzenbach S., Jensen J.A., Henckel P., Hansen-Møller J., Syriopoulos K., Byrne D.V., 2008. Effect of feeding fermentable fibre-rich feedstuffs on meat quality with emphasis on chemical and sensory boar taint in entire male and female pigs. *Meat Sci.* 80, 1165–1173, <https://doi.org/10.1016/j.meatsci.2008.05.010>
- He J., Xie H., Chen D., Yu B., Huang Z., Mao X., Zheng P., Luo Y., Yu J., Luo J., Yan H., 2021. Synergetic responses of intestinal microbiota and epithelium to dietary inulin supplementation in pigs. *Eur. J. Nutr.* 60, 715–727, <https://doi.org/10.1007/s00394-020-02284-3>
- Henchion M., McCarthy M., Resconi V.C., Troy D., 2014. Meat consumption: Trends and quality matters. *Meat Sci.* 98, 561–568, <https://doi.org/10.1016/j.meatsci.2014.06.007>
- Herosimczyk A., Lepczyński A., Werkowska M. et al., 2022. Dietary inclusion of dried chicory root affects cecal mucosa proteome of nursery pigs. *Animals* 12, 1710, <https://doi.org/10.3390/ani12131710>
- Higgins J.P.T., Thompson S. G., 2002. Quantifying heterogeneity in a meta-analysis. *Stat. Med.* 21, 1539–1558, <https://doi.org/10.1002/sim.1186>
- Higgins J.P., Thompson S.G., Spiegelhalter D.J., 2009. A re-evaluation of random-effects meta-analysis. *J. R. Stat. Soc. Ser. A Stat. Soc.* 172, 137–159, <https://doi.org/10.1111/j.1467-985X.2008.00552.x>
- Hu Y., Chen D., Yu B., et al., 2020. Effects of dietary fibres on gut microbial metabolites and liver lipid metabolism in growing pigs. *J. Anim. Physiol. Anim. Nutr.* 104, 1484–1493, <https://doi.org/10.1111/jpn.13429>
- Hughes J.M., Oiseth S.K., Purslow P.P., Warner R.D., 2014. A structural approach to understanding the interactions between colour, water-holding capacity and tenderness. *Meat Sci.* 98, 520–532, <https://doi.org/10.1016/j.meatsci.2014.05.022>
- Ivarsson E., Liu H.Y., Dicksved J., Roos S., Lindberg J.E., 2012. Impact of chicory inclusion in a cereal-based diet on digestibility, organ size and faecal microbiota in growing pigs. *Anim. Int. J. Anim. Biosci.* 6, 1077–1085, <https://doi.org/10.1017/S1751731111002709>
- Jayasooriya S.D., Pluske J.R., Dunshea F.R., Gill H., Ponnampalam E.N., 2009. Dietary iron improves iron status in finisher pigs fed wheat based diets. *Manipulating Pig Production XII Proceedings of the Twelfth Biennial Conference of the Australasian Pig Science Association (APSA)*. Australasian Pig Science Association, ISBN 978-0-9806880-0-9
- Jolliff J., Mahan D., 2012. Effect of dietary inulin and phytase on mineral digestibility and tissue retention in weanling and growing swine. *Anim. Sci.* 90, 3012–3022, <https://doi.org/10.2527/jas.2011-4424>
- Joo S.T., Kim G.D., Hwang Y.H., Ryu Y.C., 2013. Control of fresh meat quality through manipulation of muscle fiber characteristics. *Meat Sci.* 95, 828–836, <https://doi.org/10.1016/j.meatsci.2013.04.044>

- Kozłowska I., Marć-Pieńkowska J., Bednarczyk M., 2016. Beneficial aspects of inulin supplementation as a fructooligosaccharide prebiotic in monogastric animal nutrition—a review. *Ann Anim. Sci.* 16, 315–331, <https://doi.org/10.1515/aoas-2015-0090>
- Lan Q., Lian Y., Peng P., Yang L., Zhao H., Huang P., Ma H., Wei H., Yin Y., Liu M., 2023. Association of gut microbiota and SCFAs with finishing weight of Diannan small ear pigs. *Front. Microbiol.* 14, 1117965, <https://doi.org/10.3389/fmicb.2023.1117965>
- Lee J.H., Kim S., Kim E.S., et al., Kim H.B., 2023. Comparative analysis of the pig gut microbiome associated with the pig growth performance. *J. Anim. Sci. Technol.* 65, 856–864, <https://doi.org/10.5187/jast.2022.e122>
- Lefaucheur L., 2010. A second look into fibre typing - Relation to meat quality. *Meat Sci.* 84, 257–270, <https://doi.org/10.1016/j.meatsci.2009.05.004>
- Lefaucheur L., Ecolan P., Plantard L., Gueguen N., 2002. New insights into muscle fiber types in the pig. *J. Histochem. Cytochem.* 50, 719–730, <https://doi.org/10.1177/002215540205000513>
- Lepczyński A., Herosimczyk A., Barszcz M., Ożgo M., Michałek K., Grabowska M., Tuśnio A., Szczerbińska D., Skomial J., 2021. Diet supplemented either with dried chicory root or chicory inulin significantly influence kidney and liver mineral content and antioxidative capacity in growing pigs. *Animal* 15, 100129, <https://doi.org/10.1016/j.animal.2020.100129>
- Li H., Yin J., Tan B., Chen J., Zhang H., Li Z., Ma X., 2021. Physiological function and application of dietary fiber in pig nutrition: A review. *Anim. Nutr.* 7, 259–267, <https://doi.org/10.1016/j.aninu.2020.11.011>
- Li Y., Li J., Zhang L., Yu C., Lin M., Gao F., Zhou G., Zhang Y., Fan Y., Nuldnali L., 2015. Effects of dietary energy sources on post mortem glycolysis, meat quality and muscle fibre type transformation of finishing pigs. *PLoS ONE* 10, e0131958, <https://doi.org/10.1371/journal.pone.0131958>
- Lin-Schilstra L., Backus G., Snoek H., Mörlein D., 2022. Consumers' view on pork: consumption motives and production preferences in ten European Union and four non-European Union countries. *Meat Sci.* 187, 108736, <https://doi.org/10.1016/j.meatsci.2022.108736>
- Liu B., Han R.H., Hao H., Wang Z., Yong F., Li H., Zhang T., Yang L., Jiang H., Che D., 2024. Interaction of dietary fiber and soluble to insoluble dietary fiber ratio in improving production performance, meat quality and muscle fiber type transformation in finishing pigs. <https://doi.org/10.2139/ssrn.4907781>
- Liu N., Shen H., Zhang F., Liu X., Xiao Q., Jiang Q., Tan B., Ma X., 2023. Applications and prospects of functional oligosaccharides in pig nutrition: a review. *Anim Nutr.* 13, 206–215, <https://doi.org/10.1016/j.aninu.2023.02.002>
- Liu Y., Espinosa C.D., Abelilla J.J., Casas G.A., et al., 2018. Non-antibiotic feed additives in diets for pigs: a review. *Anim Nutr.* 4, 113–125, <https://doi.org/10.1016/j.aninu.2018.01.007>
- Loh G., Eberhard M., Brunner R.M., Hennig U., Kuhla S., Kleessen B., Metges C.C., 2006. Inulin alters the intestinal microbiota and short-chain fatty acid concentrations in growing pigs regardless of their basal diet. *J. Nutr.* 136, 1198–1202, <https://doi.org/10.1093/jn/136.5.1198>
- Luo R., Song X., Li Z., Zhang A., Yan X., Pang Q., 2018. Effect of soil salinity on fructan content and polymerization degree in the sprouting tubers of Jerusalem artichoke (*Helianthus tuberosus* L.). *Plant Physiol. Biochem.* 125, 27–34, <https://doi.org/10.1016/j.plant.2021.100281>
- Lynch M.B., Sweeney T., Callan B.F.J.J., O'Doherty J.V., 2007. The effect of high and low dietary crude protein and inulin supplementation on nutrient digestibility, nitrogen excretion, intestinal microflora and manure ammonia emissions from finisher pigs. *Animal* 1, 1112–1121, <https://doi.org/10.1017/S1751731107000407>
- Ma J., Piao X., Mahfuz S., Long S., Wang J., 2022. The interaction among gut microbes, the intestinal barrier and short chain fatty acids. *Anim. Nutr.* 9, 159–174, <https://doi.org/10.1016/j.aninu.2021.09.012>
- MacFabe D.F., Cain D.P., Rodriguez-Capote K., Franklin A.E., Hoffman J.E., Boon F., Taylor A.R., Kavaliers M., Ossenkopp K.P., 2007. Neurobiological effects of intraventricular propionic acid in rats: possible role of short chain fatty acids on the pathogenesis and characteristics of autism spectrum disorders. *Behav. Brain Res.* 176, 149–169, <https://doi.org/10.1016/j.bbr.2006.07.025>
- Mach N., Berri M., Estellé J., et al., 2015. Early-life establishment of the swine gut microbiome and impact on host phenotypes. *Environ Microbiol Rep.* 7, 554–569, <https://doi.org/10.1111/1758-2229.12285>
- Mair C., Pletzner C., Domig K.J., Schedle K., Windisch W., 2010. Impact of inulin and a multispecies probiotic formulation on performance, microbial ecology and concomitant fermentation patterns in newly weaned piglets. *J. Anim. Physiol. Anim. Nutr.* 94, 164–177e, <https://doi.org/10.1111/j.1439-0396.2010.01000.x>
- Mancini R.A., Hunt M.C., 2005. Current research in meat color. *Meat Sci.* 71, 100–121, <https://doi.org/10.1016/j.meatsci.2005.03.003>
- McCormack U.M., Curião T., Metzler-Zebeli B.U., Wilkinson T., Reyer H., Crispie F., Cotter P.D., Creevey C.J., Gardiner G.E., Lawlor P.G., 2019. Improvement of feed efficiency in pigs through microbial modulation via fecal microbiota transplantation in sows and dietary supplementation of inulin in offspring. *Appl. Environ. Microbiol.* 85, e01255–19, <https://doi.org/10.1128/AEM.01255-19>
- Meerza S.I.A., Gulab S., Brooks K.R., Gustafson C.R., Yiannaka A., 2022. U.S. consumer attitudes toward antibiotic use in livestock production. *Sustainability.* 14, 7035, <https://doi.org/10.3390/su14127035>
- Metzler-Zebeli B.U., Trevisi P., Prates J.A.M., Tanghe S., Bosi P., Canibe N., Montagne L., Freir J., Zebeli Q., 2017. Assessing the effect of dietary inulin supplementation on gastrointestinal fermentation, digestibility and growth in pigs: A meta-analysis. *Anim. Feed Sci. Technol.* 233, 120–132, <https://doi.org/10.1016/j.anifeedsci.2017.05.010>
- Miao M., Dai Y., Ru C., Fan Y., Wang X., Fan C., Mu J., Hou W., Dong Z., Li P., Sun G., Zeng X., 2021. Dietary supplementation of inulin alleviates metabolism disorders in gestational diabetes mellitus mice via RENT/AKT/IRS/GLUT4 pathway. *Diabetol. Metab. Syndr.* 13, 150, <https://doi.org/10.1186/s13098-021-00768-8>
- Mikkelsen L.L., Jakobsen M., Jensen B.B., 2003. Effects of dietary oligosaccharides on microbial diversity and fructo-oligosaccharide degrading bacteria in faeces of piglets post-weaning. *Anim. Feed. Sci. Technol.* 109, 133–150, [https://doi.org/10.1016/S0377-8401\(03\)00172-X](https://doi.org/10.1016/S0377-8401(03)00172-X)
- Niness K.R., 1999. Inulin and oligofructose: what are they? *J. Nutr.* 129, 1402–1406, <https://doi.org/10.1093/jn/129.7.1402S>
- Nowak P., Kaspruwicz-Potocka M., Zaworska A. et al., 2017. The effect of eubiotic feed additives on the performance of growing pigs and the activity of intestinal microflora. *Arch. Anim. Nutr.* 71, 455–469, <https://doi.org/10.1080/1745039X.2017.1390181>
- OECD/ Food and Agriculture Organization of the United Nations, 2023. "Meat", in OECD-FAO Agricultural Outlook 2023–2032, OECD Publishing, Paris, <https://doi.org/10.1787/08801ab7-en>

- Oh J.K., Chae J.P., Pajarillo E.A.B., Kim S.H., Kwak M.J., Eun J.S., Chee S.W., Whang K.Y., Kim S.H., Kang D.K., 2020. Association between the body weight of growing pigs and the functional capacity of their gut microbiota. *Anim. Sci. J.* 91, e13418, <https://doi.org/10.1111/asj.13418>
- Ojima M. N., Yoshida K., Sakanaka M., Jiang L., Odamaki T., Katayama T., 2022. Ecological and molecular perspectives on responders and non-responders to probiotics and prebiotics. *Curr. Opin. Biotechnol.* 73, 108–120, <https://doi.org/10.1016/j.copbio.2021.06.023>
- Øverland M., Kjos, N.K., Fauske A.K., Teige J., Sørum H., 2011. Easily fermentable carbohydrates reduce skatole formation in the distal intestine of entire male pigs. *Livest. Sci.* 40, 206–217, <https://doi.org/10.1016/j.livsci.2011.03.032>
- Patience J.F., Ramirez A., 2022. Invited review: strategic adoption of antibiotic-free pork production: the importance of a holistic approach. *Transl. Anim. Sci.* 6, txac063, <https://doi.org/10.1093/tas/txac063>
- Patterson J.K., Yasuda K., Welch R.M., Miller D.D., Lei X.G., 2010. Supplemental dietary inulin of variable chain lengths alters intestinal bacterial populations in young pigs. *J. Nutr.* 140, 2158–2161, <https://doi.org/10.3945/jn.110.130302>
- Paudel B., Kolady D., Grebitus C., Roy A., Ishaq M., 2022. Consumers' willingness to pay for pork produced with different levels of antibiotics. *Q Open* 2, qoac001, <https://doi.org/10.1093/qopen/qoac001>
- Pierce K.M., Callan J.J., McCarthy P., O'Doherty J.V., 2005. Performance of weanling pigs offered low or high lactose diets supplemented with avilamycin or inulin. *Anim. Sci.* 80, 313–318, <https://doi.org/10.1079/ASC40900313>
- Ponnampalam E., Jayasooriya D., Gill H., Pluske J.R., Dunshea F.R., 2009. Nutritional manipulation of iron level in finisher pigs and fresh pork. Final Report (3A-108) prepared for the Cooperative Research Centre for an Internationally Competitive Pork Industry
- Przybylski W., Jaworska D., Sałek P., Sobol M., Branicki M., Skiba G., Raj S., Jankiewicz U., 2019. The effect of inulin supply to high-fat diet rich in saturated fatty acids on pork quality and profile of sarcoplasmic protein in meat exudate. *J. Anim. Physiol. Anim. Nutr.* 103, 593–602, <https://doi.org/10.1111/jpn.13039>
- Purslow P.P., Gagaoua M., Warner R. D., 2021. Insights on meat quality from combining traditional studies and proteomics. *Meat Sci.*, 174, 108423, <https://doi.org/10.1016/j.meatsci.2020.108423>
- Qin Y.Q., Wang L.Y., Yang X.Y., Xu Y.J., Fan G., Fan Y.G., Ren J.N., Li Q.X., 2023. Inulin: properties and health benefits. *Food Funct.* 14, 2948, <https://doi.org/10.1039/D2FO01096H>
- Richardson M., Garner P., Donegan S., 2019. Interpretation of subgroup analyses in systematic reviews: A tutorial. *Clin. Epidemiol. Glob. Health* 7, 192–198, <https://doi.org/10.1016/j.cegh.2018.05.005>
- Roberfroid M.B., 2005. Introducing inulin-type fructans. *Br. J. Nutr.* 93, (Suppl 1), 13–25, <https://doi.org/10.1079/BJN20041350>
- Roberfroid M.B., 2007. Inulin-type fructans: functional food ingredients. *J. Nutr.* 137, 2493–2502, <https://doi.org/10.1093/jn/137.11.2493S>
- Roberfroid M.B., Vanloo J.A.E., Gibson G.R., 1998. The bifidogenic nature of chicory inulin and its hydrolysis products. *J. Nutr.* 128, 11–19, <https://doi.org/10.1093/jn/128.1.11>
- Rosenvold K., Andersen H.J., 2003. The significance of pre-slaughter stress and diet on colour and colour stability of pork. *Meat Sci.* 63, 199–209, [https://doi.org/10.1016/S0309-1740\(02\)00071-2](https://doi.org/10.1016/S0309-1740(02)00071-2)
- Rosenvold K., Essen-Gustavsson B., Andersen H. J., 2003. Dietary manipulation of pro- and macroglycogen in porcine skeletal muscle. *J. Anim. Sci.* 81, 130–134, <https://doi.org/10.2527/2003.811130x>
- Rosenvold K., Lærke H.N., Jensen S.K.; Karlsson A.H., Lundström K., Andersen H.J., 2001a. Strategic finishing feeding as a tool in the control of pork quality. *Meat Sci.* 59, 397–406, [https://doi.org/10.1016/S0309-1740\(01\)00092-4](https://doi.org/10.1016/S0309-1740(01)00092-4)
- Rosenvold K., Lærke H. N., Jensen S. K., Karlsson A. H., Lundström K., Andersen H. J., 2002. Manipulation of critical quality indicators and attributes in pork through vitamin E supplementation, muscle glycogen reducing finishing feeding and preslaughter stress. *Meat Sci.* 62, 485–496, [https://doi.org/10.1016/S0309-1740\(02\)00045-1](https://doi.org/10.1016/S0309-1740(02)00045-1)
- Rosenvold K., Petersen J. S., Lærke H. N., Jensen S. K., Therkildsen M., Karlsson A. H., Møller H. S., Andersen H. J., 2001b. Muscle glycogen stores and meat quality as affected by strategic finishing feeding of slaughter pigs. *J. Anim. Sci.* 79, 382–391, <https://doi.org/10.2527/2001.792382x>
- Samolińska W., Grela E.R., 2017. Comparative effects of inulin with different polymerization degrees on growth performance, blood trace minerals, and erythrocyte indices in growing-finishing pigs. *Biol. Trace Elem. Res.* 176, 130–142, <https://doi.org/10.1007/s12011-016-0796-y>
- Samolińska W., Grela E.R., Kiczorowska B., 2019. Effects of inulin extracts and inulin-containing plants on haematobiochemical responses, plasma mineral concentrations, and carcass traits in growing-finishing pigs. *J. Elem.* 24, 711–726, <https://doi.org/10.5601/jelem.2018.23.4.1707>
- Samolińska W., Kowalczyk-Vasilev E., Grela E.R., 2018. Comparative effect of different dietary inulin sources and probiotics on growth performance and blood characteristics in growing-finishing pigs. *Arch. Anim. Nutr.* 72, 379–395, <https://doi.org/10.1080/1745039X.2018.1505147>
- San Andres J.V., Mastromano G.A., Li Y., Tran H., Bundy J.W., Miller P.S., Burkey T.E., 2019. The effects of prebiotics on growth performance and in vitro immune biomarkers in weaned pigs. *Transl. Anim. Sci.* 3, 1315–1325, <https://doi.org/10.1093/tas/txz129>
- Schafer A., Rosenvold K., Purslow P. P., Andersen H. J., Henckel P., 2002. Physiological and structural events post mortem of importance for drip loss in pork. *Meat Sci.* 61, 355–366, [https://doi.org/10.1016/S0309-1740\(01\)00205-4](https://doi.org/10.1016/S0309-1740(01)00205-4)
- Scheffler T.L., Gerrard D.E., 2007. Mechanisms controlling pork quality development: The biochemistry controlling postmortem energy metabolism. *Meat Sci.* 77, 7–16, <https://doi.org/10.1016/j.meatsci.2007.04.024>
- Shen Q.W., Means W. J., Thompson S.A., Underwood K.R., Zhu M.J., McCormick R.J., Ford S.P., Du M., 2006. Pre-slaughter transport, AMP activated protein kinase, glycolysis, and quality of pork loin. *Meat Sci.* 74, 388–395, <https://doi.org/10.1016/j.meatsci.2006.04.007>
- Shoaib M., Shehzad A., Omar M., Rakha A., Raza H., Sharif H.R., Shakeel A., Ansari A., Niazi S., 2016. Inulin: Properties, health benefits and food applications. *Carbohydr. Polym.* 147, 444–454, <https://doi.org/10.1016/j.carbpol.2016.04.020>
- Sobol M., Raj S., Skiba G., 2018. Inulin supplementation reduces the negative effect of a high-fat diet rich in SFA on bone health of growing pigs. *Br. J. Nutr.* 119, 1111–1118, <https://doi.org/10.1017/S0007114518000764>
- Sobolewska S., Grela E.R., 2014. The effect of inulin extraction method or powder from inulin-producing plants in fatter diets on performance, carcass traits and meat quality. *Ann. Anim. Sci.* 14, 911–920, <https://doi.org/10.2478/a0as-2014-0046>

- Sobolewska S., Grela E.R., 2015. Effect of inulin extract or inulin-containing plant supplement on short-chain fatty acids in the large intestine and jejunum histology of fatteners. *Med. Wet.* 71, 432–435
- Stewart M.L., Timm D.A., Slavin J.L., 2008. Fructooligosaccharides exhibit more rapid fermentation than long-chain inulin in an in vitro fermentation system. *Nutr Res.* 28, 329–334, <https://doi.org/10.1016/j.nutres.2008.02.014>
- Tako E., Glahn R.P., Welch R.M., Lei X., Yasuda K., Miller D.D., 2008. Dietary inulin affects the expression of intestinal enterocyte iron transporters, receptors and storage protein and alters the microbiota in the pig intestine. *Br. J. Nutr.* 99, 472–480, <https://doi.org/10.1017/S0007114507825128>
- Tang S., Xin Y., Ma Y., Xu X., Zhao S., Cao J., 2020. Screening of microbes associated with swine growth and fat deposition traits across the intestinal tract. *Front Microbiol.* 11, 586776, <https://doi.org/10.3389/fmicb.2020.586776>
- Topping D.L., Clifton P.M., 2001. Short-chain fatty acids and human colonic function: roles of resistant starch and nonstarch polysaccharides. *Physiol Rev.* 81, 1031–1064, <https://doi.org/10.1152/physrev.2001.81.3.1031>
- Trefan L., Büniger L., Rooke J., Blom-Hansen J., Salmi B., Larzul C., Terlouw C., Doeschl-Wilson A., 2010. Meta-analysis of effects of dietary vitamin E and post slaughter storage conditions on changes of redness (a\*) of pork. *Arch. Anim. Breed.* 53, 564–577, <https://doi.org/10.5194/aab-53-564-2010>
- Varley P.F., McCarney C., Callan J.J., O'Doherty J.V., 2010. Effect of dietary mineral level and inulin inclusion on phosphorus, calcium and nitrogen utilisation, intestinal microflora and bone development. *J. Sci. Food Agric.* 90, 2447–2454, <https://doi.org/10.1002/jsfa.4105>
- Vesterinen H., Sena E., Egan K., Hirst T., Churolov L., Currie G., Antonic A., Howells D., MacLeod M., 2014. Meta-analysis of data from animal studies: A practical guide. *J. Neurosci. Methods* 221, 92–102, <https://doi.org/10.1016/j.jneumeth.2013.09.010>
- Vhile S.G., Kjos N.P., Sørum H., Øverland M., 2012. Feeding Jerusalem artichoke reduced skatole level and changed intestinal microbiota in the gut of entire male pigs. *Animal.* 6, 807–814, <https://doi.org/10.1017/S1751731111002138>
- Wang L., Huang Y., Wang Y., Shan T., 2021. Effects of polyunsaturated fatty acids supplementation on the meat quality of pigs: A meta-analysis. *Front. Nutr.* 8, 746765, <https://doi.org/10.3389/fnut.2021.746765>
- Wang W., Chen D., Yu B., Huang Z., Luo Y., Zheng P., Mao X., Yu J., Luo J., He J., 2019. Effect of dietary inulin supplementation on growth performance, carcass traits, and meat quality in growing-finishing pigs. *Animals.* 9, 840, <https://doi.org/10.3390/ani9100840>
- Wang W., Chen D., Yu B., Huang Z., Mao X., Zheng P., Luo Y., Yu J., Luo J., Yan H., He J., 2020. Effects of dietary inulin supplementation on growth performance, intestinal barrier integrity and microbial populations in weaned pigs. *Br. J. Nutr.* 124, 296–305, <https://doi.org/10.1017/S0007114520001130>
- Warner R.D., Greenwood P.L., Pethick D.W., Ferguson D.M., 2010. Genetic and environmental effects on meat quality. *Meat Sci.* 86, 171–183, <https://doi.org/10.1016/j.meatsci.2010.04.042>
- Wellock I.J., Fortomaris P.D., Houdijk J.G.M., Wiseman J., Kyriazakis I., 2008. The consequences of non-starch polysaccharide solubility and inclusion level on the health and performance of weaned pigs challenged with enterotoxigenic *Escherichia coli*. *Br. J. Nutr.* 99, 520–530, <https://doi.org/10.1017/S0007114507819167>
- Wen C., Wang Q., Gu S., Jin J., Yang N., 2024. Emerging perspectives in the gut-muscle axis: The gut microbiota and its metabolites as important modulators of meat quality. *Microb. Biotechnol.* 17, e14361, <https://doi.org/10.1111/1751-7915.14361>
- Wilborn B.S., Kerth C.R., Owsley W. F., Jones W.R., Frobish L.T., 2004. Improving pork quality by feeding supranutritional concentrations of vitamin D31. *J. Anim. Sci.* 82, 218–224, <https://doi.org/10.2527/2004.821218x>
- Wu W., Zhang L., Xia B., Tang S., Liu L., Xie J., Zhang H., 2020. Bioregional alterations in gut microbiome contribute to the plasma metabolomic changes in pigs fed with inulin. *Microorganisms* 8, 111, <https://doi.org/10.3390/microorganisms8010111>
- Xia B., Wu W., Zhang L., Wen X., Xie J., Zhang H., 2021. Gut microbiota mediates the effects of inulin on enhancing sulfomucin production and mucosal barrier function in a pig model. *Food Funct.* 12, 10967–10982, <https://doi.org/10.1039/D1FO02582A>
- Yan E., Guo J., Yin J., 2023. Nutritional regulation of skeletal muscle energy metabolism, lipid accumulation and meat quality in pigs. *Adv. Nutr.* 14, 185–192, <https://doi.org/10.1016/j.aninu.2023.04.009>
- Yang C., Lu H., Li E., Oladele P., Ajuwon K.M., 2023. Inulin supplementation induces expression of hypothalamic antioxidant defence genes in weaned piglets. *J. Anim. Physiol. Anim. Nutr.* 107, 157–164, <https://doi.org/10.1111/jpn.13698>
- Yang Y., Liu Y., Liu J., et al., 2021. Composition of the fecal microbiota of piglets at various growth stages. *Front. Vet. Sci.* 8, 661671, <https://doi.org/10.3389/fvets.2021.661671>
- Yasuda K., Dawson H.D., Wasmuth E.V., Roneker C., Chen C., Urban J.F., Welch R.M., Miller D.D., Lei X.G., 2009. Supplemental dietary inulin influences expression of iron and inflammation related genes in young pigs. *J. Nutr.* 139, 2018–2023, <https://doi.org/10.3945/jn.109.110528>
- Yasuda K., Maiorano R., Welch R.M., Miller D.D., Lei X.G., 2007. Cecum is the major degradation site of ingested inulin in young pigs. *J. Nutr.* 137, 2399–2404, <https://doi.org/10.1093/jn/137.11.2399>
- Yasuda K., Roneker K.R., Miller D.D., Welch R.M., Lei X.G., 2006. Supplemental dietary inulin affects the bioavailability of iron in corn and soybean meal to young pigs. *J. Nutr.* 136, 3033–3038, <https://doi.org/10.1093/jn/136.12.3033>
- Yin P., Du T., Yi S., Zhang Ch., Yu L., Tian F., Chen W., Zhai Q., 2023. Response differences of gut microbiota in oligofructose and inulin are determined by the initial gut Bacteroides/Bifidobacterium ratios. *Food Res. Int.* 174, 1, 113598, <https://doi.org/10.1016/j.foodres.2023.113598>
- Zhang Y., Yu B., Yu J., Zheng P., Huang Z., Luo Y., Luo J., Mao X., Yan H., He J., Chen D., 2019. Butyrate promotes slow-twitch myofiber formation and mitochondrial biogenesis in finishing pigs via inducing specific microRNAs and PGC-1 $\alpha$  expression1. *J. Anim. Sci.* 97, 3180–3192, <https://doi.org/10.1093/jas/skz187>
- Zhou H., Yu B., Sun J., Liu Z., Chen H., Ge L., Chen D., 2021. Short-chain fatty acids can improve lipid and glucose metabolism independently of the pig gut microbiota. *J. Anim. Sci. Biotechnol.* 12, 61, <https://doi.org/10.1186/s40104-021-00581-3>
- Zlowodzki M., Poolman R.W., Kerkhoffs G.M., Tornetta P., Bhandari M., 2007. How to interpret a meta-analysis and judge its value as a guide for clinical practice. *Acta Orthop.* 78, 59–609, <https://doi.org/10.1080/17453670710014284>