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Non Ruminant Nutrition

A meta-regression analysis to evaluate the effects of narasin on grow-finish pig performance

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ABSTRACT

Ionophores are feed additives that decrease gram-positive microbial populations by disrupting the ion transfer across cell membranes resulting in improved growth performance. Narasin (Skycis; Elanco Animal Health, Greenfield, IN) is an FDA-approved ionophore utilized for increased rate of weight gain and improved feed efficiency in growing-finishing pigs. A meta-regression analysis was conducted to evaluate the effects of added narasin in growing-finishing pig diets to predict its influence on average daily gain (**ADG**), feed efficiency (**G:F**), and carcass yield. A database was developed containing 21 technical reports, abstracts, and refereed papers from 2012 to 2021 representing 35 observations for growth performance data in studies ranging from 35 to 116 d in length (overall data). In addition, within these 35 observations, individual period data were evaluated (143 observations) using weekly, bi-weekly, or monthly performance intervals (period data). Regression model equations were developed, and predictor variables were assessed with a stepwise manual forward selection procedure. The ADG model using the overall data included ADG, ADFI, and G:F of the control group, added narasin dose, and narasin feeding duration categorized as longer or shorter than 65 d. Predictor variables included in the G:F model using overall data were ADG, ADFI, and G:F of the control group and added narasin dose. For carcass yield, the final model included ADFI and G:F of the control group, added narasin dose, and narasin feeding duration of longer than 65 d. In the period model for ADG, the predictors included ADG, ADFI, and G:F of the control group, added narasin dose, and average BW of the control group categorized into greater than or less than 105 kg. For period data for G:F, the model selected ADG, ADFI, and G:F of the control group and added narasin dose. Based on the results, the overall response to added narasin for ADG and G:F was quadratic and tended to decrease as ADG and G:F increased. A similar quadratic response was observed for the individual period data. In summary, using median values from the database for predictor variables, this meta-analysis demonstrated narasin would be expected to improve ADG between 1.06% and 1.65%, G:F between 0.71% and 1.71%, and carcass yield by 0.31% when fed continuously for longer than 65 d.

LAY SUMMARY

Ionophores are feed additives that alter microbial populations by disrupting ion transfer across cell membranes. Narasin is a commercially available ionophore for use in swine diets that has been evaluated in several experiments. However, no summary of current data is available to predict the expected magnitude of response when narasin is added to swine diets. Therefore, a meta-regression analysis was conducted to evaluate the effects of added narasin in growing-finishing pig diets to predict growth rate, feed efficiency, and carcass yield. The models developed suggest important variables for predicting the percentage change in growth performance and carcass yield for pigs fed diets with added narasin include the narasin feeding duration, average weight, and growth performance of pigs fed diets without narasin.

Key words: carcass yield, grow-finish pig, growth performance, ionophore, narasin

INTRODUCTION

Narasin is a polyether ionophore produced by the fermentation of *Streptomyces aureofaciens* (Berg and Hamill, 1978). Polyether ionophores have a hydrophobic region that allows them to interact with a cell's lipid bilayer and the hydrophilic region that forms binding sites for ions. The hydrophobic region allows the ionophore to pass through the lipid bilayers and once inside the cell membrane, the hydrophilic region of narasin interacts with the aqueous environment allowing it to selectively bind to the target ions, H+, K+, and Na+ (Wuethrich et al., 1998).

Narasin has a high affinity for cations such as Na+ and K+ and facilitates their transport across lipid bilayers (Caughey et al., 1986). Once narasin is bound to the K+ or Na+ ions, it shuttles them across the bacterial cell membrane, resulting in an increase in H+ concentration on the inside of gram-positive cells (Russell and Strobel, 1989). As a result, the Na+ K+ ATPase is activated to transport excess H+ out of the cell. This activation depletes the gram-positive bacteria of energy and reduces fermentative functions and cell division. The ultimate result is a reduction in the number of gram-positive bacteria (Russell and Strobel, 1989).

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As a result of a shift toward fewer gram-positive bacteria relative to gram-negative bacteria in the digestive tract, short-chain fatty acid (**SCFA**) profiles are changed (Dawson and Boling, 1983). Gram-positive bacteria produce more acetate and butyrate whereas gram-negative bacteria produce more propionate. The reduction of gram-positive bacteria increases the relative proportion of propionate to acetate and butyrate (Richardson et al., 1976; Nagaraja et al., 1987). Propionate is an end product of carbohydrate fermentation and is more desirable than other SCFAs because it is gluconeogenic (Wolin, 1981). In ruminants, increased propionate production results in increased growth and feed efficiency (Ruan et al., 1976; Bergen and Bates, 1984; Barreras et al., 2013).

Ionophores have been widely used in diets for ruminants to improve growth performance (Ruan et al., 1976). Ionophores are also used in poultry diets to aid in the control of parasitic diseases (Chapman et al., 2010) and now can be used to improve growth performance in pigs (Arkfeld et al., 2015). However, there is no summary of all available data indicating the expected magnitude of response when including ionophores, specifically narasin, in swine diets. Therefore, our objective of this meta-regression analysis was to evaluate the effects of added narasin in growing-finishing pig diets to predict the response in ADG, G:F, and carcass yield.

MATERIALS AND METHODS

Database

A literature search was conducted utilizing CAB Direct to evaluate the effects of added narasin in diets for growing-finishing pigs. Key search terms included one of the following terms: narasin, ionophore, Monteban, or Skycis (Elanco Animal Health, Greenfield, IN). In addition, Elanco Animal Health (Greenfield, IN) provided internal reports for trials with narasin fed to grow-finish pigs. Response criteria of interest from each trial were recorded in a spreadsheet template to compare the performance of pigs fed diets without narasin (control pigs) and pigs fed diets with narasin. The percentage change in response was calculated for pigs fed narasin diets relative to the control pigs. Commonly reported data included the year the study was completed, length of the trial, narasin dosage, diet composition, gender, narasin feeding duration, initial and final body weight, ADG, ADFI, G:F, hot carcass weight (**HCW**), carcass yield, backfat, percentage lean, and loin depth.

The results of the initial search yielded 24 papers. However, 3 such papers were excluded: 1 paper for observing treatment diet × gender interactions, and 2 papers for initial BW of less than 21 kg. The final database contained data from 21 papers from 2012 to 2021 representing 35 observations for growth performance data in studies ranging from 35 to 116 d in length (overall data). In addition, within these 35 observations, individual period data was evaluated (143 observations) using weekly, bi-weekly, or monthly performance intervals (period data).

Of the 21 papers included, 9 were internal reports (Elanco Animal Health, Greenfield, IN), 10 were peer-reviewed publications, and 2 were technical reports (JBS United technical bulletin and Kent Nutrition Notes).

In the final database, studies ranged from an initial BW of 23 kg to a final BW of 139 kg and the narasin feeding duration ranged from 35 to 116 d (Table 1). The database consisted of research conducted using 15, 20, or 30 mg/kg of narasin. For the overall trial data, there were a total of 35 observations with 21 observations comparing dosages of 0 to 15 mg/kg of narasin, 4 observations comparing 0 to 20 mg/kg of narasin, and 4 observations comparing 0 to 30 mg/kg of narasin. Additionally, there were 4 studies where narasin dosage increased during the study (Table 2). Dosages increased from 0 to 15 mg/kg (4 observations) or increased from 15 to 30 mg/kg (2 observations). For the carcass yield model, there were a total of 24 observations for the overall data. There were 15 observations comparing 0 to 15 mg/kg of narasin, 2 observations comparing 0 to 20 mg/kg, and 3 observations comparing 0 to 30 mg/kg. Additionally, there were 3 observations where narasin dosage increased from 0 to 15 mg/kg during the study, and 1 observation where narasin increased from 15 to 30 mg/kg during the study.

In the period database, there were a total of 143 observations. Ninety-nine of those observations were comparing 0 to 15 mg/kg, 14 observations compared 0 to 20 mg/kg, and 30 observations compared 0 to 30 mg/kg of narasin.

Statistical Analysis

Models were created with the relative change in response criteria between the control pigs and pigs fed narasin as the outcome. The period data model considered data with single continuous narasin feeding periods (weekly, bi-weekly, or monthly periods) while the overall model considered complete data sets representing periods with and without narasin feeding.

Regression equations were developed using the GLIMMIX procedure of SAS (Version 9.4, SAS institute, Cary, NC). The study was included as a random intercept when fitting models using period data due to multiple weigh periods occurring in each experiment. To begin model building, the single-variable model with the lowest Bayesian Information Criterion (**BIC**) was selected, and then additional predictor variables were assessed through a stepwise manual forward selection for final model inclusion (Holen et al., 2022). Predictor variables were required to provide an improvement of at least 2 BIC units to be included in the final model. When the model with the lowest BIC was obtained, visual assessment of studentized residual plots was performed to assess model assumptions for ADG, G:F, and carcass yield.

Regression models were developed to predict the percentage change in response for ADG, G:F, and carcass yield by comparing pigs fed diets with or without narasin. The predictor variables evaluated in the statistical model to predict the change in ADG and G:F included added narasin, feeding duration category (longer or shorter than 65 d), average BW category (less than or greater than 105 kg), days of narasin feeding, initial and final BW of the control pigs, and ADG, ADFI, and G:F of the control pigs. The same predictor variables were evaluated in the carcass yield model as the ADG and G:F models, with the addition of HCW, backfat, percentage lean, and loin depth of the control pigs. The significant predictors used in the models included ADG, ADFI, and G:F of the control group, feeding duration, added narasin dose, and average BW. The regression equations can be used to estimate the expected percentage change for ADG, G:F, and carcass yield when feeding narasin to growing-finishing pigs (Table 3).

Categories were created for feeding duration and average BW within the database. To determine ranges for each

Table 1. Effect of narasin on growth performance of growing-finishing pigs for overall data[1]

Publication	Feeding duration, d	Initial BW, kg	Final BW, kg	Change, %				
				BW	ADG	ADFI	G:F	Carcass yield
0 vs. 15 mg/kg of narasin								
Report T2NUS120004, 2012	85	48.19	121.53	0.649	0.930	−0.476	1.166	−0.054
Report 12S03, 2013	69	29.48	95.16	1.239	2.415	0.760	1.643	0.401
JBS United Report, 2013	75	61.19	128.28	0.670	1.714	−0.356	2.078	0.397
Arentson et al. (2013)	91	24.99	100.50	0.452	0.509	−1.630	2.046	0.466
Report ELAUS140179, 2014	102	39.60	124.10	3.947	1.970	3.304	−1.408	0.454
Report T2NUS130009, 2014	56	47.22	102.92	0.309	0.000	0.335	−0.549	—
Greiner et. al. (2014)	63	27.00	89.37	0.000	0.000	0.000	−0.932	—
Report ELAUS150089, 2015	98	26.26	130.14	0.697	1.070	1.031	0.247	0.432
Report ELAUS150321, 2015	35	84.41	124.78	0.582	2.926	0.402	2.772	−0.208
Knauer et al. (2015)	90	22.95	120.57	2.295	2.929	0.868	1.928	—
Arentson et al. (2016)	50	26.72	69.49	3.525	5.263	4.715	0.524	—
Edmonds (2016)	110	22.91	119.85	2.914	3.603	1.453	2.119	1.183
Rickard et al. (2017)	105	43.89	133.63	1.514	1.205	0.932	0.294	0.449
Report ELA210244, 2021	111	39.05	139.12	1.109	1.389	1.226	0.000	0.546
Report ELA210431, 2021	116	28.76	134.40	1.147	1.322	1.457	0.242	—
Report ELAVV200324, 2021	111	42.68	131.95	0.997	0.985	−0.542	1.635	−0.404
Ewing et al. (2021)	89	40.50	121.60	0.822	2.198	−1.667	3.158	0.404
Linneen et al. (2021) (Exp. 1)	109	23.28	126.38	1.256	1.378	0.233	2.361	0.671
Linneen et al., 2021 (Exp. 2)	110	26.39	129.42	1.391	1.765	0.650	1.560	0.417
Puls et al. (2021) (Exp. 1)	85	33.38	116.26	1.014	1.408	0.749	0.752	—
Puls et al. (2021) (Exp. 2)	113	28.03	123.79	1.136	0.939	−0.169	1.389	0.400
0 vs. 20 mg/kg of narasin								
JBS United Report (2013)	75	61.19	128.28	0.702	1.714	0.712	0.995	−0.397
Greiner et. al. (2014)	63	27.00	89.37	0.705	1.010	−3.930	−1.166	—
Puls et al. (2021) (Exp. 1)	85	33.38	116.26	0.819	0.939	−0.187	1.504	—
Puls et al. (2021) (Exp. 2)	113	28.03	123.79	0.623	0.469	−1.351	1.944	0.133
0 vs. 30 mg/kg of narasin								
JBS United Report (2013)	75	61.19	128.28	1.380	3.429	1.423	1.977	0.529
Arentson et al. (2016)	50	26.72	89.37	3.982	5.789	3.970	1.750	—
Report ELA210244, 2021	111	39.05	139.12	0.946	1.389	1.926	−0.792	0.137
Report ELAVV200324, 2021	111	42.68	131.95	1.272	1.478	0.181	1.090	−0.135

[1]Database contained data from 21 studies for growth performance data. The percentage change in response was calculated for pigs fed narasin diets relative to the control pigs.

category, a scatter plot was created to display the distribution and variation for each response. A natural break in the data was observed at 65 d for feeding duration and 105 kg for average BW. The feeding duration category was created with the goal of determining the effect of longer or shorter feeding durations of narasin on improving growth performance in pigs. The average BW category was created with the goal of determining the effect of feeding narasin to heavy or light-weight pigs.

RESULTS

Overall Data

Results from the overall database for improvements in ADG ranged from 0% to 5.79% with an average response of 1.61% for all narasin dosages. For the ADG model, significant predictor variables were ADG of the control pigs (quadratic), ADFI of the control pigs (quadratic), G:F of the control pigs (quadratic), added narasin dose (quadratic), and feeding duration. The observed predicted improvements in ADG were influenced by control pigs' ADG for overall data when narasin is fed for longer than 65 d. The regression curve fit based on predicted performance shows that the response to narasin is quadratic and tends to decrease as control ADG increases (Fig. 1).

The range of ADG improvement for observations comparing pigs fed a control diet vs. a diet with 15 mg/kg of narasin was 0%- to 5.26% with an average improvement of 1.71%. Results from the meta-regression analysis indicated that feeding diets with 15 mg/kg of narasin increased ADG by 1.21% when fed for longer than 65 d when using median values for control pigs (G:F, 0.379; ADG, 0.960 kg; ADFI, 2.533 kg calculated by dividing ADG and G:F). However, when feeding 15 mg/kg of narasin for less than 65 d, the meta-analysis found that ADG improved by 0.33% when using median values for control pigs (G:F, 0.413; ADG, 0.990 kg;

Table 2. Effects of narasin on growth performance when narasin inclusion rate changed over time of grow-finish pigs for overall data[1]

Publication	Trial duration, d	Initial BW, kg	Final BW, kg	Initial[2]		Final[3]		Change, %				
				Dose, mg/kg	Duration, d	Dose, mg/kg	Duration, d	BW	ADG	ADFI	G:F	Carcass yield
Report ELAUS150089, 2015	98	26.26	130.14	0	56	15	42	0.732	1.027	1.203	−0.247	−0.054
Report ELA210244, 2021	111	39.05	139.12	0	48	15	63	0.196	0.463	−0.175	0.264	−0.273
Report ELA210244, 2021	111	39.05	139.12	0	14	15	97	0.326	0.463	−0.175	0.528	0.137
Report ELA210431, 2021	116	28.76	134.40	0	57	15	59	−0.236	0.000	−0.182	0.242	—
Report ELA210431, 2021	116	28.76	134.40	15	57	30	116	0.810	1.322	0.729	0.726	—
Report ELAVV200324, 2021	111	42.68	131.95	15	56	30	111	0.859	0.985	−0.361	1.635	−0.270

[1]The percentage change in response was calculated for pigs fed narasin diets relative to the control pigs.
[2]Represents the narasin dose at the start of the research trial and how many days it was fed.
[3]Represents the narasin dose at the end of the research trial and how many days it was fed.

ADFI, 2.397 kg). Thus, indicating that a longer feeding duration of narasin results in a greater improvement of ADG.

When comparing pigs fed a control diet vs. a diet with 20 mg/kg of narasin, the range of ADG improvement was 0% to 1.71% with an average of 1.03%. The model predicts an average of 1.10% when using median values for control pigs (G:F, 0.379; ADG, 0.960 kg; ADFI, 2.533 kg) and fed for longer than 65 d. When feeding 20 mg/kg of narasin for less than 65 d, the regression predicts an improvement in ADG of 0.23%. However, within the database, there was only 1 observation where 20 mg/kg was fed for less than 65 d. Thus, further research is warranted to determine the effect of feeding 20 mg/kg of narasin for less than 65 d.

Within the database for the comparison of pigs fed a control diet vs. a diet with 30 mg/kg of narasin, the range of ADG improvement was 1.39% to 5.79% with an average of 3.02%. The model predicts an average of 1.65% when using median values for control pigs (G:F, 0.379; ADG, 0.960 kg; ADFI, 2.533 kg), and fed for longer than 65 d. When feeding 30 mg/kg of narasin for less than 65 d, the regression predicts an improvement in ADG of 0.77%. Similar to the lower dosages of narasin, the response in ADG is greater when narasin is fed for a longer feeding duration.

In summary for ADG, the regression analysis predicts an improvement in ADG of 1.21% at 15 mg/kg of added narasin, 1.10% at 20 mg/kg, and 1.65% at 30 mg/kg when fed for longer than 65 d. The raw data in the database indicated a greater improvement in ADG when 30 mg/kg of narasin is fed compared to 15 mg/kg which is in agreement with the predicted improvements from the model. However, it's important to consider the low number of observations for 30 mg/kg as compared with 15 mg/kg of narasin.

For G:F, results from the overall database ranged from −1.41% to 3.16% with an average response of 0.96% for all narasin dosages. There were two competing models with a similar fit. Model 1 had a BIC of 59.81 and included the following predictor variables: control ADG (quadratic), control ADFI (quadratic), control G:F (quadratic), and added narasin dose (quadratic). Model 2 had a BIC of 56.24 and included the same predictor variables as model 1 with the addition of narasin feeding duration. Within the database, there are only 9 observations where narasin is fed for less than 65 d. For these 9 observations, the range was from −1.17% to 2.77% with the average response being a 0.30% increase in G:F. Due to the low number of observations used in this model for short feeding duration, the regression equation predicted a negative improvement in G:F when including narasin in the diet. With only 9 observations for the short feeding duration, model 2 was not able to accurately predict improvements in G:F. Therefore, model 1 was selected as the final model (Fig. 2).

When comparing pigs fed a control diet vs. a diet with 15 mg/kg of narasin, the range of G:F improvement was −1.41% to 3.16% with an average of 1.10%. The model predicted an average of 0.99% when using median values for control pigs (G:F, 0.379; ADG, 0.966 kg; ADFI, 2.549 kg). Additionally, when comparing pigs fed a control diet vs. a diet with 20 mg/kg of narasin, the range of G:F improvement was −1.17% to 1.94% with an average of 0.82%. The model predicted an average of 1.10% when using median values for control pigs (G:F, 0.379; ADG, 0.966 kg; ADFI, 2.549 kg). In comparison to the average response of 0.82% in the database, the G:F model may slightly overpredict the response in G:F from feeding 20 mg/kg. However, it is important to consider

Table 3. Regression coefficients to predict percent change in ADG, G:F, and carcass yield for overall and period data[1]

Predictor variable:	Overall data models[2]			Period data models[3]	
	ADG, kg	G:F	Carcass yield	ADG, kg	G:F
Added narasin, g/kg					
Linear term	−194.0400	165.3000	−248.7500	−438.6600	553.2900
Quadratic term	4972.6400	−4083.2400	5265.2100	9844.2300	−12889.0000
ADG of control group, kg					
Linear term	−155.5300	−189.2000	—	−20.3343	−11.7242
Quadratic term	69.1111	93.3874	—	3.9187	3.0086
ADFI of control group, kg					
Linear term	−20.1232	−22.5132	−13.0956	−7.3680	−5.9921
Quadratic term	4.9058	4.1902	2.3828	1.5496	1.0498
G:F of control group					
Linear term	204.6900	498.2900	−9.3526	−12.8490	23.2097
Quadratic term	−198.5700	−648.0100	12.5142	26.7571	−39.5517
Feeding duration category, d	1.3140	—	1.4097	—	—
Average BW category, kg	—	—	—	−0.6774	—
Intercept	57.7410	29.4398	21.0875	31.0257	9.4187

[1]Overall data represent growth performance data in studies ranging from 35 to 116 d in length. Within the overall data, period data were evaluated using weekly, bi-weekly, or monthly performance intervals.
[2]A total of 35 observations using 15, 20, or 30 mg/kg of narasin. For the carcass yield model, there were a total of 24 observations.
[3]A total of 143 observations using 15, 20, or 30 mg/kg of narasin.

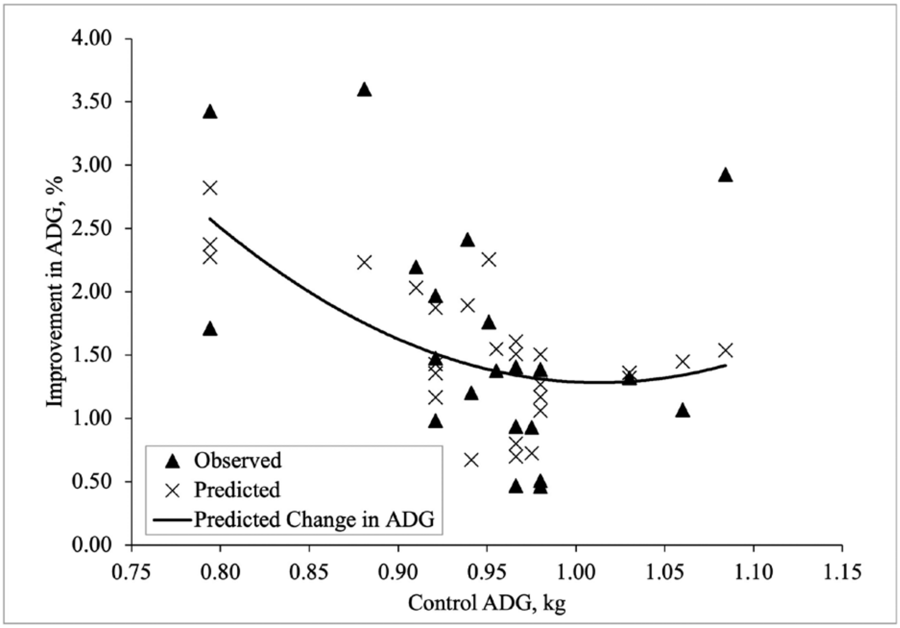

Figure 1. Observed and predicted improvements in ADG as influenced by control ADG (pigs fed 0 mg/kg narasin) for overall data when 15 mg/kg of narasin is fed for longer than 65 d. A regression curve was fitted from the predicted performance. There were a total of 21 observations comparing 0 to 15 mg/kg of narasin in the database.

there are only 4 observations in the database with doses of 20 mg/kg.

Within the database comparing pigs fed a control diet vs. a diet with 30 mg/kg of narasin, the range of G:F improvement was −0.79% to 1.98% with an average of 1.01%. The model predicted an average of 0.71% when using median values for control pigs (G:F, 0.379; ADG, 0.966 kg; ADFI, 5.549 kg). Unlike ADG, feeding 30 mg/kg of added narasin did not further improve G:F compared to 15 mg/kg of added narasin (0.71% vs. 0.99% for 30 and 15 mg/kg of added narasin, respectively).

In summary for G:F, the regression analysis predicted an improvement in G:F of 0.99% at 15 mg/kg of added narasin, 1.10% at 20 mg/kg, and 0.71% at 30 mg/kg. With the exception of the narasin dose of 20 mg/kg, the predicted improvements align with the observed raw data in the database.

Results from the overall database for improvements in carcass yield ranged from −0.40% to 1.18% with an average

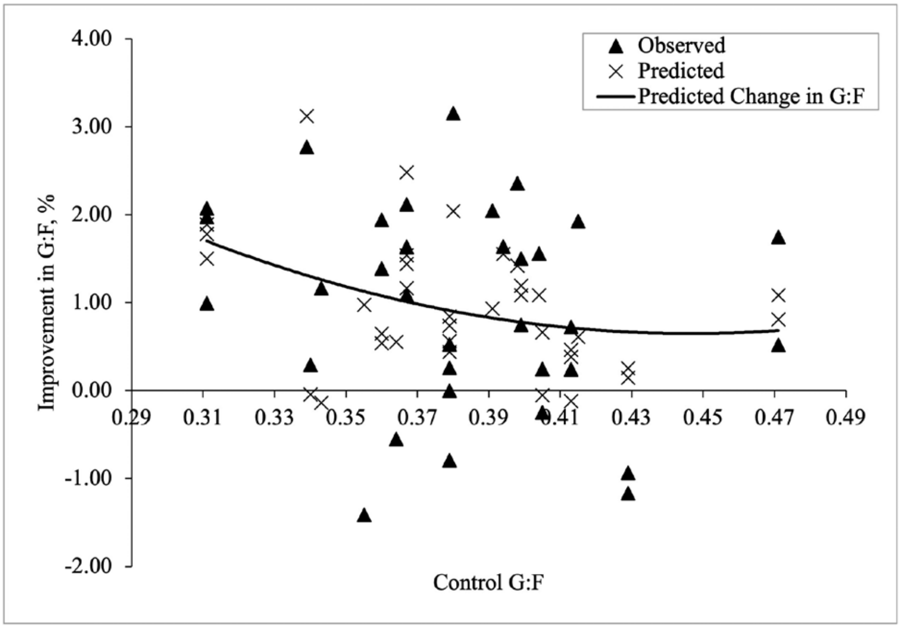

Figure 2. Observed and predicted improvements in G:F as influenced by control G:F (pigs fed 0 mg/kg of narasin) for overall data when 15 mg/kg of narasin is fed. A regression curve was fitted from the predicted performance. There were a total of 21 observations comparing 0 to 15 mg/kg of narasin in the database.

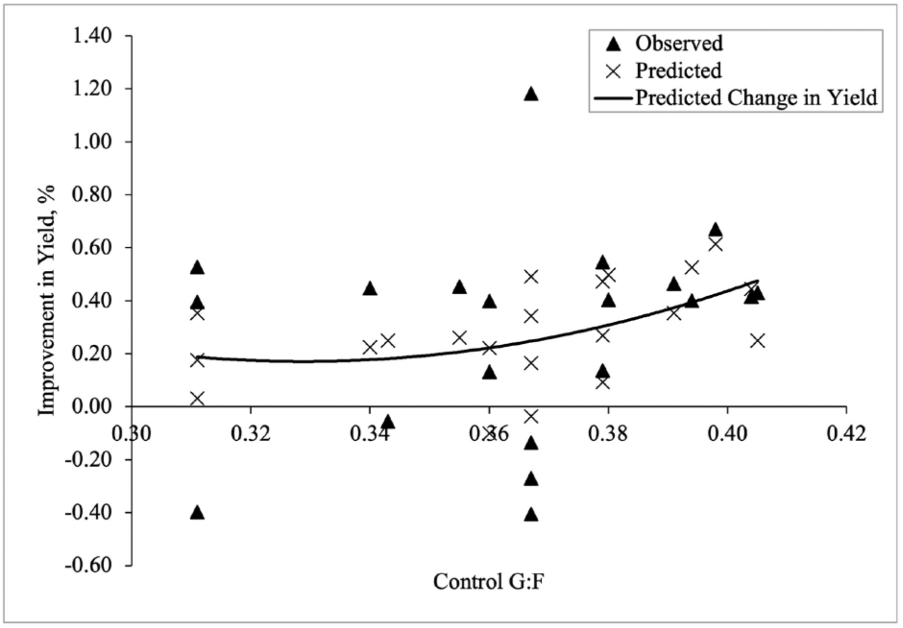

Figure 3. Observed and predicted improvements in carcass yield as influenced by control G:F (pigs fed 0 mg/kg of narasin) for overall data when 15 mg/kg of narasin is fed for longer than 65 d. A regression curve was fitted from the predicted performance. There were a total of 15 observations comparing 0 to 15 mg/kg of narasin in the database.

response of 0.22% for all narasin dosages. The predictor variables that were included in the carcass yield model were control ADFI (quadratic), control G:F (quadratic), added narasin dose (quadratic), and narasin feeding duration. The observed and predicted improvements in carcass yield as influenced by control G:F for overall data are relatively consistent as G:F increased (Fig. 3). For comparing pigs fed a control diet vs. 15 mg/kg, the range of yield improvement was −0.40% to 1.18% with an average of 0.37%. The model predicted an average of 0.31% when using median values for control pigs (G:F, 0.367; ADFI, 2.549 kg) and fed for longer than 65 d. With only 2 observations comparing a control vs. 20 mg/kg, the range of values were −0.40% and 0.13%. Thus, results from the meta-regression analysis suggest that feeding 20 mg/kg resulted in no benefit in carcass yield (−0.02%) when using median values for G:F (0.367), ADFI (2.549 kg), and narasin fed for longer than 65 d. Furthermore, when comparing a control diet vs. diet

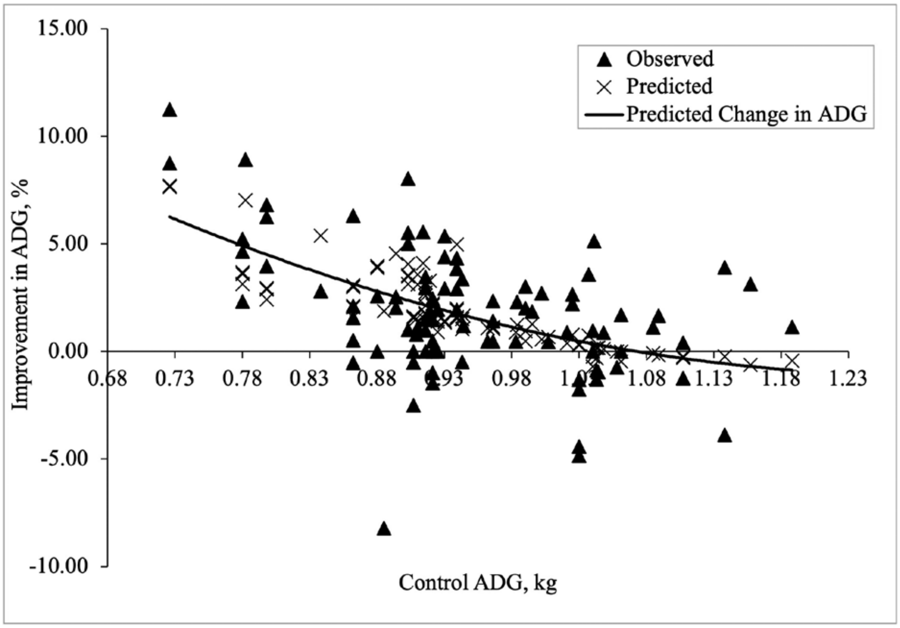

Figure 4. Observed and predicted improvements in ADG as influenced by control ADG (pigs fed 0 mg/kg of narasin) for period data when 15 mg/kg of narasin is fed to pigs lighter than 105 kg. A regression curve was fitted from the predicted performance. The individual period data considered data with single continuous narasin feeding periods (weekly, bi-weekly, or monthly periods). There were a total of 99 observations comparing 0 to 15 mg/kg of narasin in the database.

with 30 mg/kg of narasin, the range of yield improvement was −0.13% to 0.53% with an average of 0.18%. The model predicted an average of 0.13% when using median values for control pigs (G:F, 0.367; ADFI, 2.549 kg), and fed for longer than 65 d. When narasin was fed for less than 65 d at 15, 20, or 30 mg/kg, no benefit in carcass yield was predicted using the regression equations.

In summary for carcass yield, the regression analysis predicted an improvement in carcass yield of 0.31% at 15 mg/kg narasin and 0.13% at 30 mg/kg. No benefit in carcass yield was predicted when feeding 20 mg/kg of narasin.

Period Data

For results from the database consisting of period data, the improvements in ADG ranged from −9.06% to 12.86% with an average response of 1.49% for all narasin dosages. The significant predictor variables in the ADG regression equation were control ADG (quadratic), control ADFI (quadratic), control G:F (quadratic), added narasin dose (quadratic), and average body weight category. The observed and predicted improvements in ADG for period data models have less variation compared to the overall data models because there are more observations included in the period data (Fig. 4).

The range of ADG improvement when comparing a control diet vs. a diet with 15 mg/kg was the same as the overall database (−9.06% to 12.86%) with an average of 1.43%. The model predicted an average of 1.53% when fed to pigs with an average BW of less than 105 kg and using median values for control pigs (G:F, 0.400; ADG, 0.930 kg; ADFI, 2.325 kg). When feeding 15 mg/kg of narasin to pigs with an average BW of greater than 105 kg, the meta-analysis suggested an improvement in ADG of 0.57% when using median values for control pigs (G:F, 0.322; ADG, 0.953 kg; ADFI, 2.960 kg). Thus, feeding narasin to lighter BW pigs resulted in a greater improvement of ADG than heavier BW pigs when using the period data model.

Within the database comparing pigs fed a control diet vs. a diet with 20 mg/kg, the range of ADG improvement was −0.87% to 6.82% with an average of 1.46%. The model predicted an average of 1.06% when using median values for control pigs (G:F, 0.400; ADG, 0.930 kg; ADFI, 2.325 kg) with an average BW of less than 105 kg. When 20 mg/kg of narasin was fed to pigs with an average BW heavier than 105 kg, the predicted improvement in ADG was 0.10% when using median values for control pigs (G:F, 0.322; ADG, 0.953 kg; ADFI, 2.960 kg). Additionally, the range of ADG improvement for comparing a control diet vs. a diet with 30 mg/kg of narasin was −8.45% to 11.25% with an average of 1.68%. The model predicted an average of 1.59% when using median values for control pigs (G:F, 0.400; ADG, 0.930 kg; ADFI, 2.325 kg) with an average BW of less than 105 kg. When 30 mg/kg of narasin was fed to pigs with an average BW greater than 105 kg, the predicted improvement in ADG was 0.63% when using median values for control pigs (G:F, 0.322; ADG, 0.953 kg; ADFI, 2.960 kg).

In summary for ADG, the regression analysis predicted an improvement in ADG of 1.53% at 15 mg/kg of added narasin, 1.06% at 20 mg/kg, and 1.59% at 30 mg/kg when fed to pigs weighing less than 105 kg. For pigs weighing greater than 105 kg, an improvement of 0.57% at 15 mg/kg of added narasin, 0.10% at 20 mg/kg, and 0.63% at 30 mg/kg was predicted. The predicted improvements for the period ADG model aligned with the predicted changes for the overall ADG model where a slightly lower improvement was observed for 20 mg/kg of narasin compared to 15 or 30 mg/kg.

A regression equation was also developed for G:F for period data. Results from the database for improvements in G:F ranged from −4.26% to 6.80% with an average response of 1.04% for all narasin dosages. The predictor variables

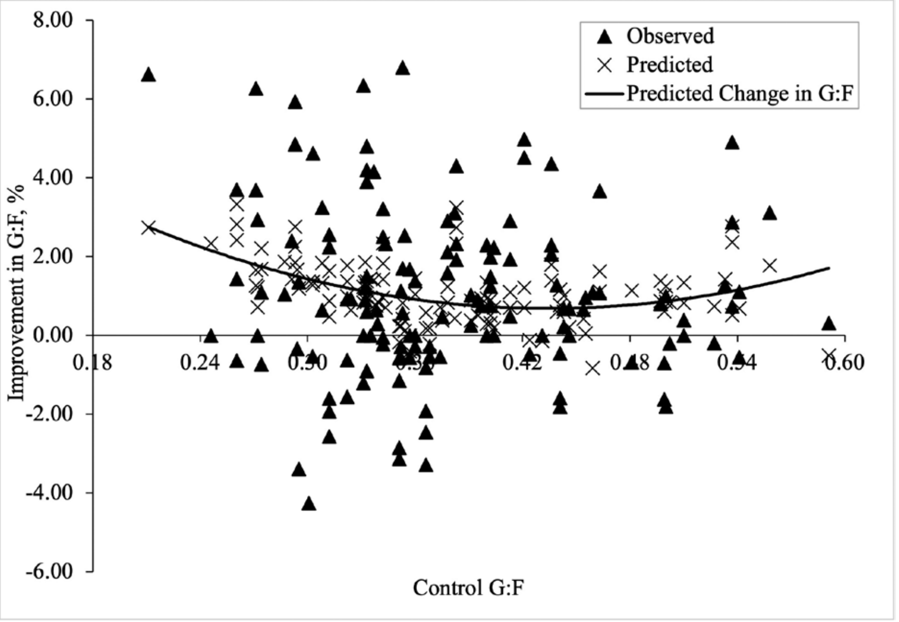

Figure 5. Observed and predicted improvements in G:F as influenced by control G:F (pigs fed 0 mg/kg of narasin) for period data when pigs were fed 15 mg/kg of narasin. A regression curve was fitted from the predicted performance. The individual period data model considered data with single continuous narasin feeding periods (weekly, bi-weekly, or monthly periods). There were a total of 99 observations comparing 0 to 15 mg/kg of narasin in the database.

included in the G:F regression equation were control ADG (quadratic), control ADFI (quadratic), and control G:F (quadratic), and added narasin dose (quadratic). The observed and predicted improvement in G:F that was influenced by control G:F for period data had a quadratic response to narasin and tended to decrease as G:F increased (Fig. 5). Within the database, the range of G:F improvement for comparing pigs fed a control vs. 15 mg/kg of narasin was −4.26% to 6.80% with an average of 0.95%. The model predicted an average of 1.20% when using median values for control pigs (G:F, 0.363; ADG, 0.939 kg; ADFI, 2.587 kg).

When comparing a control diet vs. a diet with 20 mg/kg of narasin, the range of G:F improvement was −0.64% to 5.94% with an average of 1.89%. The model predicted an average of 1.71% when using median values for control pigs (G:F, 0.363; ADG, 0.939 kg; ADFI, 2.587 kg). Furthermore, for the comparison of a control vs. 30 mg/kg of narasin, the range of G:F improvement for pigs fed 30 mg/kg of narasin was −2.85% to 6.34% with an average of 0.92%. The model predicted an average of 0.80% when using median values for control pigs (G:F, 0.363; ADG, 0.939 kg; ADFI, 2.587 kg).

In summary for G:F, the regression model predicted an improvement in G:F of 1.20% at 15 mg/kg inclusion of narasin, 1.71% at 20 mg/kg, and 0.80% at 30 mg/kg. The predicted improvements for the period G:F model align with the predicted improvements for the overall G:F model where a slightly greater improvement was observed for 20 mg/kg of narasin compared to 15 mg/kg.

DISCUSSION

Narasin improves the efficiency of microbial fermentation in the gut leading to increased production of SCFAs, specifically propionate, which are used as energy sources by the pig (Wuethrich et al., 1998). Propionate production is more desirable because it is energy efficient as the liver converts propionate to glucose which can be utilized as an energy source (Wolin, 1981; Wuethrich et al., 1998). Research conducted on ruminants has shown that increased propionate production resulted in increased growth and feed efficiency (Ruan et al., 1976). The same result can be expected in swine because of the similar microbial environment (Salanitro et al., 1977). Therefore, ADG and feed efficiency are included as predictor variables in the regression models because of the effect narasin has on improving nutrient utilization, resulting in enhanced feed conversion and growth performance.

The overall ADG model resulted in a similar predicted response to narasin compared to the raw data in the database (1.21% vs. 1.71% for model prediction and raw data, respectively for 15 mg/kg of added narasin). The period model for ADG also resulted in a similar predicted response to narasin compared to the raw data in the database (1.53% vs. 1.43% for model prediction and raw data, respectively for 15 mg/kg of added narasin).

The ADG response to narasin is quadratic and gradually decreased as ADG increased. This response was observed in both the overall model and period model (Figs. 1 and 4, respectively). Narasin provides a greater benefit in terms of improving ADG in poorer-performing pigs indicating that the SCFA shift toward propionate production is translated to improvements in growth more readily in poor-performing pigs which are in a high demand for energy. However, when pigs have high ADG, they are already efficiently converting propionate and dietary contents to energy resulting in a lesser benefit to narasin.

The overall G:F model resulted in a similar predicted response to narasin compared to the raw data in the database (0.99% vs. 1.10% for model prediction and raw data, respectively for 15 mg/kg narasin of added). For the ADG period model when comparing to the raw data, the model may be overpredicting the response to narasin (1.20% vs. 0.95% for model prediction and raw data, respectively for 15 mg/kg narasin dose). This may be due to the variation that occurs during individual growth periods consisting of weekly, bi-weekly, or monthly performance intervals.

The G:F response to narasin is quadratic and decreased then increased as G:F improved for both the overall and period model (Figs. 2 and 5, respectively). This could be due to limited observations at low or high G:F of control pigs. For example, in Fig. 2, the overall database consisted of 2 observations with low G:F of 0.31 and 2 observations with high G:F of 0.47. With limited data at the extremes for G:F, the response to narasin is driven to be quadratic because of the influence of these 4 observations. Furthermore, there is more variation in the response to narasin for the period data compared to the overall data (Fig. 5).

Narasin also has the ability to influence carcass yield because of the effect on growth performance and energy utilization. When pigs have improved growth rates and high lean muscle development, it can contribute to increased carcass yield. In the database, there were 24 total observations reported for carcass yield. Sixteen observations reported increased carcass yield when narasin was added to the diet with 13 of those observations reporting improvements in feed efficiency and ADG. The improved growth performance is due to the effect narasin has on microbial fermentation resulting in increased energy production. The pig can utilize the energy toward increasing carcass weight rather than viscera weight. An increase in carcass weight results in increased carcass yield. Furthermore, research suggests that improved growth performance due to increased energy utilization increased HCW and positively benefited carcass yield (Smith et al., 1999; De la Llata et al., 2007; Bromm et al., 2023).

However, in the regression models, the benefit in carcass yield was only observed when narasin was fed for longer than 65 d. Narasin may provide cumulative growth benefits when supplemented over extended periods of time. The prolonged duration allows for continued inhibition of gram-positive bacteria and increased proportions of propionate production allowing for continued improvements in energy utilization and improved growth (Russell and Strobel, 1989).

In conclusion, this meta-regression analysis used available data to develop regression equations for predicting the percentage change in ADG, G:F, and carcass yield when feeding narasin to growing-finishing pigs. Important predictors used in the different models included ADG, ADFI, and G:F of the control group in the studies, feeding duration, added narasin dose, and average BW. These regression equations can be used to estimate the expected percent change for ADG, G:F, and carcass yield when feeding narasin to finishing pigs using production system-specific performance estimates.

IMPLICATIONS

By using median values from the database for predictor variables, this meta-analysis demonstrated narasin would be expected to improve ADG between 1.06% and 1.65%, G:F between 0.71% and 1.71%, and carcass yield by 0.31% when fed for longer than 65 d.

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Conflict of interest statement

The authors declare no conflict of interest; however, Jenna Seltzer, Roger Arentson, and Michael Shields are employees, and Christopher Puls was an employee of Elanco Animal Health (Greenfield, IN USA) who contributed financial support and the internal research for this project.

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