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Non Ruminant Nutrition

NON RUMINANT NUTRITION

Intrinsic phytase in hybrid rye increases the digestibility of phosphorus in corn and soybean meal in diets fed to growing pigs

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Abstract

An experiment was conducted to test the hypothesis that inclusion of hybrid rye in diets containing corn and soybean meal (**SBM**) without or with microbial phytase improves the apparent total tract digestibility (**ATTD**) and the standardized total tract digestibility (**STTD**) of P because of the intrinsic phytase activity in hybrid rye. Forty-eight growing barrows (initial body weight: 39.5 ± 7.7 kg) were allotted to six diets. A basal diet containing corn and SBM; a rye-based diet; and a diet containing corn, SBM, and rye were formulated. Each diet was formulated without and with microbial phytase (500 units/kg of diet) for a total of six diets. Fecal samples were collected for 4 d following a 5-d adaptation period according to the marker-to-marker procedure. Results indicated that no interactions between diets and concentration of phytase were observed for any of the response criteria measured. The ATTD and STTD of P and the ATTD of Ca differed ($P < 0.05$) among diets, but regardless of diet, the concentration of P in feces was reduced ($P < 0.05$) by adding microbial phytase to the diets. As a consequence, microbial phytase increased ($P < 0.05$) ATTD and STTD of P, and the ATTD of Ca was also increased ($P < 0.05$) by the use of microbial phytase. Measured values for the ATTD and STTD of P in the diets containing corn, SBM, and hybrid rye without or with phytase were greater ($P < 0.05$) than values that were predicted based on the ATTD and STTD of P for the corn–SBM and the hybrid rye diet. The observation that STTD predicted from the individual ingredients underestimated the STTD of P in the mixed diet indicates that the intrinsic phytase in hybrid rye resulted in increased digestibility of the P in the corn and SBM included in the corn–SBM–hybrid rye diet. In conclusion, microbial phytase increased the ATTD and STTD of P and the ATTD of Ca regardless of feed ingredients used in diets fed to pigs. In addition, the intrinsic phytase from hybrid rye increased the ATTD and STTD of P in corn and SBM.

Key words: digestibility, intrinsic phytase, microbial phytase, phosphorus, pig, rye

Introduction

Swine diets are formulated primarily with plant feed ingredients, and most grains and oilseeds have a high concentration of phytate-bound P relative to total P because phytate is the main storage form of P in plants (Eeckhout and De Paepe, 1994). However, pigs cannot utilize most of the phytate-bound P because intestinal glands in pigs do not secrete enough endogenous phytase (Adeola and Cowieson, 2011). Therefore, adding inorganic phosphate, microbial phytase, or a combination of inorganic phosphate and microbial phytase to diets fed to

Abbreviations

ATTD	apparent total tract digestibility
SBM	soybean meal
SID	standardized ileal digestible
STTD	standardized total tract digestibility

pigs is a common practice when formulating pig diets (Selle and Ravindran, 2008). The ability of microbial phytase to improve P digestibility in diets based on plant feed ingredients fed to pigs has been demonstrated in numerous studies (Mroz et al., 1994; Akinmusire and Adeola, 2009; Casas and Stein, 2015).

Rye contains considerable quantities of intrinsic phytase (Rodehutscord et al., 2016; McGhee and Stein, 2019), which is likely the reason for the greater digestibility of P in hybrid rye than in most other cereal grains if microbial phytase is not used (McGhee and Stein, 2019). Intrinsic phytases in wheat and population-type rye increased the ATTD of P in wheat and rye that contained no intrinsic phytase (Zimmermann et al., 2003), indicating that the intrinsic phytase in small grains may act on other ingredients in the diet. It is, therefore, possible that the intrinsic phytase in hybrid rye may also increase P digestibility in other plant feed ingredients by releasing P from the phytate. However, to our knowledge, no data demonstrating that the intrinsic phytase in hybrid rye may release P from other dietary ingredients have been reported. Therefore, the objective of this experiment was to test the hypothesis that inclusion of hybrid rye in diets containing corn and soybean meal (**SBM**), without or with microbial phytase, improves the apparent total tract digestibility (**ATTD**) and the standardized total tract digestibility (**STTD**) of P. As a consequence, the second hypothesis was that ATTD and STTD of P are not additive in a mixed diet that contains hybrid rye.

Materials and Methods

The Institutional Animal Care and Use Committee at the University of Illinois reviewed and approved the protocol for the experiment.

Animals and housing

Forty-eight growing barrows (initial body weight: 39.5 ± 7.7 kg) that were the offspring of Line 359 males and Camborough females (Pig Improvement Company, Hendersonville, TN) were housed individually in metabolism crates (1.57 × 0.86 × 0.76 m) equipped with a nipple drinker, a feeder, a slatted floor, solid sides, and a screen floor for fecal collection. The metabolism crates were made from galvanized steel. Pigs were allotted to six diets using a randomized complete block design with two blocks of 24 pigs and 4 pigs per diet in each block. Therefore, there were eight pigs per treatment.

Diets, feeding, and sample collection

A basal diet containing corn and SBM; a hybrid rye-based diet (hybrid rye, sourced from KWS Lochow GmbH, Bergen, Germany); and a diet containing corn, SBM, and hybrid rye were formulated (Table 1). Each diet was formulated without and with microbial phytase (500 units/kg of diet; Quantum Blue, AB Vista, Marlborough, UK). Therefore, there were a total of six diets. Vitamins and minerals, except Ca and P, were included in all diets to meet or exceed the current requirement estimates for growing pigs (NRC, 2012). Most digestible amino acids in the diets containing rye were below the requirement and digestible Lys, Met, Thr, Trp, and Val in the diets containing corn and SBM were below the requirements. Pigs were fed at 2.7 times the energy requirement for maintenance (i.e., 197 kcal/kg × body weight$^{0.60}$; NRC, 2012), which was provided each day in two equal meals at 0800 and 1600 hours. All diets were fed in a meal form and water was available at all times. Feed disappearance was recorded daily, and pigs were fed their respective diets for 12 d. The initial 5 d was the adaptation period to the diet, and feces were collected quantitatively for 4 d using the marker-to-marker approach (Adeola, 2001). Briefly, fecal collection was initiated when the first color marker (i.e., indigo carmine), which was added to the morning meal on day 6, appeared in the feces. Collection of feces ceased when the second marker (i.e., ferric oxide), which was added to the morning meal on day 10, appeared in the feces of pigs. Orts were collected daily and fecal samples were stored at −20 °C after collection. At the conclusion of the experiment, fecal samples were dried in a forced-air oven at 50 °C. The weight of feces after drying was recorded and used to calculate digestibility values. Before analysis, the dried fecal samples were ground through a 1-mm screen in a Wiley Mill (Model 4; Thomas Scientific, Swedesboro, NJ) to obtain a homogenous subsample of feces.

Chemical analysis

Ingredient, diet, and fecal samples were analyzed for dry matter (method 930.15; AOAC Int., 2007), and ingredient and diet samples were also analyzed for ash (method 942.05; AOAC Int., 2007). The concentration of N in diet and ingredient samples was analyzed using the combustion procedure (method 999.03; AOAC Int., 2007) on a LECO FP628 protein analyzer (LECO Corp., Saint Joseph, MI). Aspartic acid was used as a calibration standard, and crude protein was calculated as 6.25 × N. Phytase activity in diets and ingredients was determined (Phytex Method, Version 1; Eurofins, Des Moines, IA). The detection limit of phytase activity was 70 units/kg. Phytic acid in ingredient samples was also analyzed (Ellis et al., 1977). Concentrations of P and Ca in ingredient, diet, and fecal samples were analyzed using inductively coupled plasma-optical emissions spectrometry (ICP-OES; method 985.01 A, B, and C; AOAC Int., 2007) after wet ash sample preparation (method 975.03 B(b); AOAC Int., 2007).

Calculations

Values for ATTD of Ca, P, and dry matter, and for STTD of P in each diet, were calculated as previously outlined (Almeida and Stein, 2010). The endogenous loss of P was assumed to be 190 mg per kg of dry matter intake (NRC, 2012), and this value was used to correct ATTD values for endogenous losses to calculate the STTD of P in each diet (Almeida and Stein, 2010). The predicted values for ATTD and STTD of P in the two diets based on corn, SBM, and hybrid rye without and with microbial phytase were calculated from the ATTD and STTD of P in the corn–SBM and the hybrid rye diets. This was accomplished by using the proportional contribution of P to the diet in which corn, SBM, and hybrid rye were included (Adeola, 2001). The proportional contributions were calculated using analyzed P in corn, SBM, and rye and the inclusion rate in the mixed diets :

$$\text{Proportional contribution} = \frac{(\text{P from the corn-SBM or the hybrid rye})}{(\text{total P in the corn-SBM-hybrid rye diet})},$$

where the concentration of P is expressed in percent, and the sum of the proportional contributions from the corn–SBM diet and from hybrid rye is 1.00.

Table 1. Ingredient and chemical compositions of experimental diets, as-fed basis

Phytase:	0 unit/kg of diet			500 units/kg of diet		
Item	Corn–SBM	Hybrid rye	Mixed[1]	Corn–SBM	Hybrid rye	Mixed
Ingredient, %						
Ground corn	76.90	—	38.70	76.40	—	38.20
Soybean meal	20.00	—	10.00	20.00	—	10.00
Rye	—	95.60	48.00	—	95.10	48.00
Soybean oil	2.00	3.00	2.00	2.00	3.00	2.00
Ground limestone	0.55	0.85	0.75	0.55	0.85	0.75
Salt	0.40	0.40	0.40	0.40	0.40	0.40
Vitamin–mineral premix[2]	0.15	0.15	0.15	0.15	0.15	0.15
Phytase premix[3]	—	—	—	0.50	0.50	0.50
Analyzed composition, %						
Dry matter, %	87.63	86.81	87.35	87.19	87.11	87.20
Crude protein, %	15.61	9.16	11.79	16.06	9.11	12.32
Ash, %	3.20	2.33	2.74	3.08	2.56	2.60
Ca, %	0.25	0.37	0.30	0.27	0.35	0.27
Total P,%	0.28	0.24	0.26	0.28	0.24	0.26
Phytate	0.83	0.61	0.72	0.83	0.61	0.72
Phytate P[4]	0.23	0.17	0.20	0.23	0.17	0.20
Nonphytate P[4]	0.05	0.07	0.06	0.05	0.07	0.06
Phytase, units/kg	<70	1,700	890	500	2,100	1,500
Calculated values, %						
SID Lys[5]	0.67	0.22	0.45	0.67	0.22	0.45
SID Met	0.23	0.11	0.17	0.23	0.11	0.17
SID Thr	0.48	0.18	0.33	0.48	0.18	0.33
SID Trp	0.16	0.07	0.11	0.16	0.07	0.11
SID Val	0.63	0.29	0.46	0.63	0.29	0.46

[1]Mixed, diet containing corn, SBM, and hybrid rye.
[2]The vitamin–micromineral premix provided the following quantities of vitamins and micro minerals per kg of complete diet: vitamin A as retinyl acetate, 11,150 IU; vitamin D_3 as cholecalciferol, 2,210 IU; vitamin E as selenium yeast, 66 IU; vitamin K as menadione nicotinamide bisulfate, 1.42 mg; thiamin as thiamine mononitrate, 1.10 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride, 1.00 mg; vitamin B_{12}, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.6 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper chloride; Fe, 125 mg as iron sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese hydroxychloride; Se, 0.30 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc hydroxychloride.
[3]Phytase premix contained 98% corn or rye and 2% phytase (5,000 phytase units/g; Quantum Blue, AB Vista, Marlborough, UK) and, therefore, provided 500 phytase units/kg diet.
[4]Phytate P was calculated by multiplying the analyzed phytate by 0.282 (Tran and Sauvant, 2004). Nonphytate P was calculated as the difference between total P and phytate P.
[5]SID, standardized ileal digestible. Values were calculated from NRC (2012).

Predicted values for the ATTD and STTD of P in the mixed diets were then calculated using the following equation:

$$\begin{aligned}\text{Predicted value, } \% = & \ (\text{ATTD of P in corn-SBM diet} \\ & \times \text{C from corn and SBM}) \\ & + (\text{ATTD of P in hybrid rye} \times \text{C from hybrid rye}),\end{aligned}$$

where C represents the proportional contribution of P to the mixed diets, and all values except for the proportional contribution are percentage (modified from Adeola, 2001). Predicted values for the STTD of P in the mixed diets were calculated as for the ATTD of P.

Statistical analysis

The normality of data was verified using the UNIVARIATE procedure (SAS Institute Inc., Cary, NC). Outliers were identified as values that deviated from the treatment mean by more than three times the interquartile range (Tukey, 1977). Data were analyzed using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC). The pig was the experimental unit for all analyses. The model included phytase, ingredient, and the interaction between phytase and ingredient as fixed effects and block and replicate (i.e., pig) within block as random effects. Least-squares means were calculated using the LSMEANS statement, and means were separated using the PDIFF option and Tukey–Kramer adjustment if the model was significant. The *t*-test was used to test the hypothesis that the difference between the measured and predicted values for the ATTD and STTD of P in the two mixed diets without or with phytase was equal to 0. Results were considered significant or a tendency at $P \leq 0.05$ and $P \leq 0.10$, respectively.

Results

Pigs remained healthy during the experiment and very little feed refusals were observed. There were four pigs that were identified as outliers. In all four cases, the amount of excreted P or Ca in feces was much greater compared with other pigs with similar feed intake and weight of feces. Phytase activity in rye used in this experiment was 2,300 units/kg, whereas corn and SBM contained less than 70 units/kg (Table 2). There were no interactions between diets and phytase for any

Table 2. Analyzed composition of feed ingredients, as-is basis

Item	Corn	Soybean meal	Hybrid rye
Dry matter, %	86.93	88.87	86.99
Crude protein, %	6.37	46.09	9.87
Ash, %	0.88	6.50	1.28
Ca, %	< 0.01	0.29	0.03
Total P, %	0.21	0.60	0.25
Phytate	0.67	1.58	0.64
Phytate P[1]	0.19	0.45	0.18
Nonphytate P[1]	0.02	0.15	0.07
Phytase, units/kg	< 70	< 70	2,300

[1]Phytate P was calculated by multiplying the analyzed phytate by 0.282 (Tran and Sauvant, 2004). Nonphytate P was calculated as the difference between total P and phytate P.

response criteria (Table 3). Feed intake and the ATTD of dry matter were greater ($P < 0.05$) for pigs fed the mixed diet than pigs fed the rye diet. However, P intake and P in feces (g/d and percent) were less ($P < 0.05$) from pigs fed the hybrid rye diet than from pigs fed the corn–SBM diet, and the ATTD and STTD of P were greater ($P < 0.05$) in the hybrid rye diet than in the corn–SBM diet. Regardless of diet, feed intake and fecal output of pigs and the ATTD of dry matter were not affected by supplementation of microbial phytase, but the concentration of P in feces was reduced ($P < 0.05$) by adding microbial phytase to the diets, which resulted in increased ($P < 0.001$) ATTD and STTD of P. Ca intake was greater ($P < 0.05$) for pigs fed the mixed diet or the rye diet than for pigs fed the corn–SBM diet. In contrast, the ATTD of Ca was greater ($P < 0.05$) for the mixed diet than for the corn–SBM diet. The output of Ca (g/d and percent) was reduced ($P < 0.05$) by microbial phytase, which resulted in an increase ($P < 0.05$) in the ATTD of Ca if microbial phytase was added to the diet. Measured values for the ATTD and the STTD of P in the two diets containing corn, SBM, and hybrid rye without and with phytase were greater ($P < 0.05$) than predicted values (Table 4).

Discussion

Concentrations of P, phytate-bound P, and Ca in corn, SBM, and hybrid rye used in this experiment were in agreement with previous data (NRC, 2012; McGhee and Stein, 2019). The elevated level of intrinsic phytase that was analyzed in hybrid rye is in agreement with data demonstrating greater intrinsic phytase activity in rye compared with other cereal grains (Rodehutscord et al., 2016). High levels of intrinsic phytase were also analyzed in different sources of hybrid rye (McGhee and Stein, 2019), but the phytase activity in hybrid rye is relatively less compared with the population-type rye used in previous experiments (Rodehutscord et al., 2016). However, differences in phytase activity among different hybrids of hybrid rye have been demonstrated (McGhee and Stein, 2019).

To calculate STTD, an average value for the basal endogenous loss of P (i.e., 190 mg/kg dry matter intake; NRC, 2012) was used to correct ATTD values for endogenous losses because there is limited variation in the basal endogenous loss of P among experiments (NRC, 2012). Observed values for the ATTD and STTD of P in the corn–SBM diet and in hybrid rye without and with microbial phytase that were calculated in this experiment were in line with previous data (Almeida et al., 2013; She et al., 2018b; McGhee and Stein, 2019; Rosenfelder-Kuon et al., 2020). The greater ATTD and STTD of P in the hybrid rye diet compared with the corn–SBM diet are likely a result of the increased phytase activity in hybrid rye.

Phytic acid is the principal storage form of P in cereal grains and oilseed meals, but the utilization of phytate P is low because pigs do not secrete sufficient quantities of phytase to degrade dietary phytate (Adeola and Cowieson, 2011). Phytate in plant feed ingredients may bind dietary Ca from other feed ingredients including calcium carbonate, and thus, an indigestible Ca–phytate complex is formed in the intestinal tract of pigs (González-Vega et al., 2013; Lee et al., 2019). However, microbial phytase can hydrolyze the ester bonds that bind P to the inositol ring in phytate, which results in increased digestibility of both P and Ca (Almeida et al., 2013; Rutherfurd et al., 2014; Lee et al., 2019), which was also observed in this experiment. No interactions between diets and exogenous phytase for the digestibility of Ca and P were observed in this experiment, although diets contained different quantities of phytate P. This indicates that corn, SBM, or hybrid rye contains more substrate than what can be fully hydrolyzed by 500 units/kg diet of microbial phytase. Therefore, the STTD of P in diets containing hybrid rye; corn and SBM; or corn, SBM, and hybrid can likely be further increased if a greater amount of phytase is supplemented to the diets. Indeed, when a broken-line model was used, between 1,000 and 2,000 units of phytase was needed to maximize the ATTD or STTD of Ca and P in corn–SBM diets (Almeida et al., 2013; She et al., 2018a; Arredondo et al., 2019). However, to the best of our knowledge, experiments to demonstrate the dose of microbial phytase needed to maximize STTD of P in hybrid rye or diets containing corn, SBM, and hybrid rye have not been conducted.

The observation that the ATTD of P was greater in the diet containing corn, SBM, and hybrid rye without microbial phytase compared with the predicted ATTD of P in this diet indicates that the ATTD of P in corn and SBM was increased by the intrinsic phytase in hybrid rye. Whereas the STTD of P is considered additive in complete diets, values for the ATTD of P in feed ingredients are not always additive due to differences in contributions of endogenous P to the fecal output (Kwon, 2016; She et al., 2018b). Therefore, to remove the confounding effects of endogenous P in feces, additivity of values for STTD of P was also calculated. The observation that STTD of P in the corn–SBM–hybrid rye diet was greater than what was predicted from the corn–SBM and the hybrid rye diets demonstrates that the intrinsic phytase in rye also increased the STTD of P in corn and SBM. We are not aware of previous data demonstrating this effect of hybrid rye, but the intrinsic phytases in wheat and rye increased the ATTD of P in wheat and rye that contained no intrinsic phytase (Zimmermann et al., 2003). However, the effects of intrinsic phytase in wheat and barley on the ATTD of P in corn and SBM were less predictable (Rodehutscord et al., 1996; Poulsen et al., 2019). This discrepancy may be a result of lower concentration of phytase in wheat and barley compared with hybrid rye. Feed processing may also reduce the activity of the intrinsic phytase contained in cereals (Jongbloed and Kemme, 1990; Weremko et al., 1997).

The observation that when microbial phytase was added to the diets containing corn, SBM, and hybrid rye, the ATTD and STTD of P were greater than predicted from the corn–SBM and the hybrid rye diets, indicates that intrinsic phytase from rye may act synergistically with microbial phytase. This implies that the synergetic effects of intrinsic phytase from some feed ingredients should be taken into consideration when formulating diets for pigs. The observation that the difference between measured and predicted values in the diet with

Table 3. ATTD and STTD of P and ATTD of Ca in experimental diets

Phytase:	0 unit/kg of diet			500 units/kg of diet				P-value		
Item	Corn–SBM	Hybrid rye	Mixed[1]	Corn–SBM	Hybrid rye	Mixed	SEM	Diet	Phytase	Diet × Phytase
n	7	7	8	7	7	8	—	—	—	—
Feed intake, kg/d	1.64	1.64	1.80	1.71	1.61	1.73	0.22	0.015	0.862	0.372
Dried fecal output, kg/d	0.12	0.17	0.15	0.13	0.17	0.13	0.02	<0.001	0.568	0.328
ATTD of dry matter, %	91.8	89.1	90.7	91.8	89.0	91.5	0.5	<0.001	0.581	0.675
Phosphorus										
P intake, g/d	4.56	3.88	4.66	4.75	3.86	4.49	0.58	<0.001	0.982	0.303
P in feces, %	2.12	1.19	1.45	1.33	0.73	0.92	0.11	<0.001	<0.001	0.328
P output, g/d	2.55	1.89	2.24	1.74	1.19	1.23	0.26	0.004	<0.001	0.657
ATTD of P, %	44.1	51.9	52.0	63.4	69.1	72.3	3.3	0.036	<0.001	0.889
STTD[2] of P, %	50.1	58.8	58.4	69.3	76.0	78.7	3.3	0.022	<0.001	0.888
Calcium										
Ca intake, g/d	4.22	5.44	5.63	4.40	5.37	5.42	0.69	<0.001	0.792	0.442
Ca in feces, %	1.22	0.94	1.08	0.82	0.68	0.64	0.15	0.075	<0.001	0.649
Ca output, g/d	1.46	1.56	1.68	1.09	1.16	0.88	0.38	0.837	<0.001	0.328
ATTD of Ca, %	65.8	72.5	70.5	75.5	79.5	84.0	4.2	0.038	<0.001	0.489

[1]Mixed, diet containing corn, SBM, and rye.
[2]Values for the STTD of P were calculated by correcting the ATTD of P with the basal endogenous loss of P (190 mg/kg dry matter intake; NRC, 2012).

Table 4. Difference between determined and predicted values for ATTD and STTD of P in the mixed diets[1,2]

Item, %	Measured	Predicted	Difference[3]	SE	P-value
ATTD of P					
Without phytase	52.0	47.7	4.3	1.3	0.007
With phytase	72.3	66.0	6.4	1.7	0.003
STTD of P					
Without phytase	58.4	54.1	4.3	1.3	0.007
With phytase	78.7	72.4	6.4	1.7	0.003

[1]*n* = 8.
[2]Mixed diets contained corn, soybean meal, and hybrid rye.
[3]Difference was calculated by subtracting predicted values from determined values.

microbial phytase supplementation was not less than in the diet without microbial phytase indicates that even with both intrinsic and microbial phytase, maximum hydrolysis of P in phytate was not achieved. This is consistent with the observation that the measured STTD of P in the diet with microbial phytase was 78.7%, indicating that some phytate-bound P was left in the diet. Therefore, it appears that to achieve full destruction of phytate in a diet containing corn, SBM, and hybrid rye, and therefore, full release of P from phytate, more than 500 units/kg diet of microbial phytase is needed. However, additional research is needed to verify this speculation.

The advantage of using values for STTD rather than ATTD in diet formulation is well established because STTD values are additive in mixed diets containing feed ingredients with no intrinsic phytase (NRC, 2012; She et al., 2018b). The basal endogenous loss of P is on average 190 mg/kg dry matter intake—and this value does not change much among experiments (NRC, 2012), which is the reason this value was used to correct ATTD values for endogenous P in this experiment. However, results demonstrate that the concept is different if hybrid rye (and likely other ingredients containing intrinsic phytase) is mixed with ingredients that do not contain intrinsic phytase, because the intrinsic phytase in one ingredient affects the digestibility of P in other ingredients. The implication of this observation is that if ingredients containing intrinsic phytase are used in diets that also contain ingredients without intrinsic phytase, the STTD values for the ingredients that do not contain intrinsic phytase need to be adjusted for the phytase originating from the ingredient with intrinsic phytase. However, additional research is needed to quantify this effect.

Conclusions

Supplementation of microbial phytase increased the ATTD and STTD of P and the ATTD of Ca in corn–SBM and hybrid rye-based diets. However, because of the intrinsic phytase in hybrid rye, the ATTD and STTD of P in corn and SBM were increased if hybrid rye was included in the diet, and this effect was observed both in the absence and in the presence of supplemented microbial phytase. Values for the ATTD or STTD of P in mixed diets containing hybrid rye were, therefore, greater than calculated from the ATTD or STTD values from the individual ingredients. This observation demonstrates that the intrinsic phytase in hybrid rye is well utilized by pigs and will increase the STTD of P in ingredients that do not contain intrinsic phytase. As a consequence, STTD values for ingredients containing no intrinsic phytase need to be adjusted in diet formulations if an ingredient with intrinsic phytase is included in the diet.

Acknowledgments

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Conflict of interest

The authors declare that they have no conflicts of interest.

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