平成31年1月10日

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飼料の公定規格における追加事項の要望について

1．　背景

平成３０年９月１８日の農業資材審議会飼料分科会における審議の結果、MorphΔE8 BP17 4c株を利用して生産されたフィターゼ（製品名：Axtra PHY（アクストラファイ））は、組換えDNA技術応用飼料添加物として、安全性に問題ないとすることは適当であると認める答申が農林水産大臣宛に出されております（30資審第11号）。

また、飼料の公定規格には、「（５）環境負荷低減型配合飼料」に非フィチン態りんの成分量の最小量（%）の規定、及び「第２章アミノ酸および非フィチン態りんの成分量並びに可消化養分総量等の値の計算方法、２　配合飼料の非フィチン態りんの成分量」には、現在指定されている４種類のフィターゼ（フィターゼ（その１）、フィターゼ（その２（１））、フィターゼ（その２（２））及びフィターゼ（その２（３）））に関し、配合飼料において各フィターゼによる分解の結果生じる非フィチン態りん（%）の算出方法の規定があります（飼料の公定規格、農林省告示７５６号）。

2．　要望内容

MorphΔE8 BP17 4c株を利用して生産されたフィターゼを、上記第２章２の規定に追加して頂き、その規定をもって養豚飼料が配合設計されることにより、排泄物中のりん含量を低減する「環境負荷低減型配合飼料」に貢献したいと考えています。具体的には、以下の算出方法を第２章２の規定に追加して頂きたく、要望いたします。

フィターゼの種類	算出方法
同（１４０） MorphΔE8 BP17 4c株を利用して生産されたフィターゼ	飼料1ｋｇあたり500フィチン酸分解力単位を添加した場合、0.14%

３． 参考資料

社内データ

① Axtra®PHY The complete phytase solution.

② Technical report Axtra PHY Meta.S.80

文献

① A.L. Wealleans, R.M.Bold, Y.Dersjant-Li, and A.Awati.

J. Anim. Sci. 2015. 93: 5283-5290.,

The addition of a *Buttiauxella sp.* Phytase to lactating sow diets deficient in phosphorus and calcium reduces weight loss and improves nutrient digestibility. （査読あり）

② Y. Dersjant-Li, A.L. Wealleans, L.P. Barnard, S. Lane.

Animal Feed Science and Technology 2017. 234: 101-109

Effect of increasing *Buttiauxalla* phytase dose on nutrient digestability and performance in weand piglets fed corn or wheat based diets. (査読あり)

③ Y. Dersjant-Li, R. M. Bold. And W. Li. Danisco Animal Nutrition, Dupont Industrial Biosciences, Marlborough, Unites Kingdom.

J. Anim, Sci Vol.94, E-Suppl. 5 page 443.

The effect of increasing in piglets: Meta-analysis from 5 trial studies.

３．　参考資料

社内データ

① Axtra®PHY　The complete phytase solution.

② Technical report Axtra PHY Meta.S.80

文献

① A.L. Wealleans, R.M.Bold, Y.Dersjant-Li, and A.Awati.
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J.　Anim, Sci Vol.94, E-Suppl. 5 page 443.
The effect of increasing in piglets: Meta-analysis from 5 trial studies.

各資料の要約

社内データ

① Axtra®PHY　The complete phytase solution.

基本的な考え方は Phyzyme XP と同じで、実際に豚を利用した [redacted] の消化試験により AxtraPHY がフィチン酸を分解し、P の消化率をどの程度増加させ、非フィチン態 P としてどの程度貢献するか、添加量に幅をもたせ、重回帰分析によってメタ解析から算出した。消化試験は以下のような内容である。

[redacted]

- 最終的にフィターゼによって貢献される有効 P は、増加した P の消化率にフィターゼ無添加の飼料中の全 P を乗じて、さらに 1.28 を乗ずることによって求めた。

フィターゼを 500 単位添加した結果生じる非フィチン態りん（=有効 P）の計算方法

有効 P (%)＝飼料中の全 P%×フィターゼの添加により改善した P 消化率/100×1.28

＊1.28 は、豚の栄養学から考慮した一般的な P の消化率の逆数

実測計算式　0.1371＝ 0.45 ×23.81/100 ×1.28

0.14 ≒

② Technical Report

AxtraPHY.Meta.S.80

- 体重 9kg 程度の離乳子豚 380 匹を使用し、40kg まで飼育する間、陽性対照区と陰性対照区（P、Ca を低減）を設定し、陰性対照区に AxtraPHY を 250-2000 単位まで段階的に添加した。
- 飼料設計は、とうもろこし、小麦、大豆粕、大麦を使用した。
- P と Ca の消化率と、排泄物中の P を求めた。
- AxtraPHY の段階的な添加により、P 消化率は陰性対照区と比較し、39.7%～60.9%ま

で改善した。

- 排泄物中Pは、陰性対照区と比較し、段階的に34.0%～51.6%まで減少した。

文献

① The addition of a *Buttiauxalla sp.* Phytase to lactating sow diets deficient in phosphorus and calcium reduce weight loss and improves nutrient digestibility. = Technical Report, PHY.Meta.SO.42 と同等

- 3つの国（オランダ、カナダ、アメリカ）で行われた合計6種類の試験で、母豚271頭を使用し、結果をメタ解析した。
- 試験区は、陽性対照区、陰性対照区、陰性対照区にAxtraPHYを250～2000単位まで段階的に添加した区を設けた。陰性対照区は、平均0.16%の有効Pを低減した。
- 飼料設計は、とうもろこし、メイズ、大豆粕、小麦、大麦を使用した。
- 測定項目は、体重、消化エネルギー、消化性P、消化性Ca
- 消化性Pは、250単位、500単位、1000単位、2000単位のそれぞれの添加によって、陰性対照区と比較して、38.5%、61.5%、69.2%、69.2%改善された。

② Effect of increasing *Buttiauxella* phytase dose on nutrient digestibility and performance in weaned piglets fed corn or wheat based diets.

- イギリスの研究機関とダニスコの共同試験として行われた離乳子豚合計 100 匹を使用した2つの代謝試験の結果を纏めた。
- 試験区は、陽性対照区、陰性対照区、陰性対照区にAxtraPHYを500、1000、2000単位/kg飼料添加した区を設けた。陰性対照区は消化性P 0.14%（試験1）、0.15%（試験2）を低減した。
- 飼料設計は、試験1はとうもろこし、大豆粕主体で、試験2は小麦、大豆粕主体。
- 測定項目は、各栄養素の見かけの消化率および成長成績。
- Pの見かけの消化率は、AxtraPHYの段階的な添加によって改善され、成長成績は陽性対照区と同等以上となった。
- 試験1では、500単位のAxtraPHYの添加により、最大0.17%の全Pが貢献できることが確認された。0.17%の全Pは、0.16%の有効Pとなる。
- 試験2では、2000単位のAxtraPHYの添加により、最大0.24%の全Pが貢献できることが確認された。0.24%の全Pは、0.22%の有効Pとなる。

③ The effect of increasing *Buttiauxella* phytase dose on performance in piglets: Meta-analysis from 5 trial studies.

- 5 つの試験データを統合して、子豚における AxtraPHY による効果を評価した。
- 平均体重 10kg の計 364 匹の子豚を使用し、合計 234 のデータポイントをメタ解析した。
- 試験区は、陽性対照区（充足した栄養成分）、陰性対照区（Ca 0.15%減、P 0.19%減）、陰性対照区＋500、1000、2000 単位/kg のフィターゼを添加した区を設けた。
- 試験飼料の原料構成は、とうもろこし、大豆粕、小麦/大麦を使った飼料で、各穀類とフィターゼ単位に相互作用がないため、データ全体をプールし統計処理をした。（Turkey's HSD）
- フィターゼ 500 単位の添加によって、飼料中 0.19%の有効 P と 0.15%の Ca と置き換え可能であることをデータが示した。
- 陰性対照区にフィターゼの添加単位を 1000～2000 に増加させることによって、さらなる P の増加による成長改善も期待できることが示唆された。
- 陽性対照区よりも、陰性対照区にフィターゼを添加したほうが、コストが節約できた。
- 結論として、AxtraPHY は、2000 単位まで子豚の生産に利益をもたらすことが示された。

社内データ 2

Axtra® PHY improves phosphorus digestibility and reduces total tract phosphorus excretion in weaned piglets (meta-analysis)

Benefits in weaned piglet diets

Phytase breaks down the anti-nutrient phytate to release phosphorus and other key nutrients such as calcium, energy and amino acids. As a result, the addition of Axtra® PHY at 2000 FTU/kg in the diet:

- **improves total tract phosphorus digestibility by 60.9% compared to the negative control**
- **improves total tract phosphorus digestibility by 24.5% compared to the positive control**
- **reduces total tract phosphorus excretion by 51.6% compared to the negative control**
- **reduces total tract phosphorus excretion by 53.5% compared to the positive control**

Design

Number: 380 | Type: weaned piglets | Treatments: 6
Phytate P level %: 0.22 | Trial length: ~9-40 kg

Treatment

- Positive control
- Negative control (NC)
- NC + Axtra® PHY at 250 FTU/kg
- NC + Axtra® PHY at 500 FTU/kg
- NC + Axtra® PHY at 1000 FTU/kg
- NC + Axtra® PHY at 2000 FTU/kg

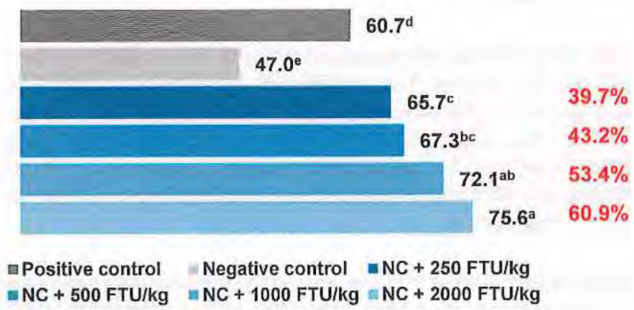
See appendix for detailed breakdown

Trial site

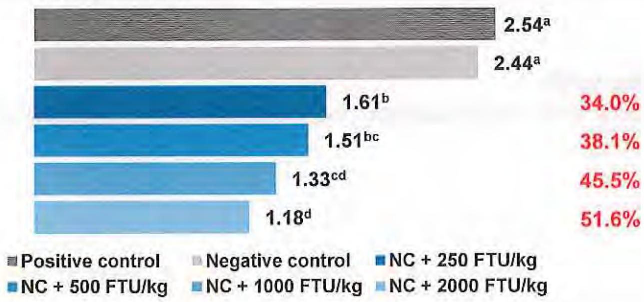
Combination of 7 trials

Results

TOTAL TRACT PHOSPHOSUS DIGESTIBILITY
(%, 9-40 kg)



TOTAL TRACT PHOSPHOSUS EXCRETION
(g/kg, 9-40 kg)



[abc] Values without a common superscript are significantly different ($P<0.05$)

What is Axtra® PHY?
Phytase breaks down the anti-nutrient phytate to release phosphorus and other digestible nutrients such as calcium, energy, amino acids and trace minerals. As a consequence of the additional release of these nutrients parameters such as bone ash, bone strength, bodyweight gain, egg mass, egg production and feed utilisation can be improved [1,2,3,4,5,6,7].

Summary

Seven trials were conducted to evaluate the effect of Axtra® PHY at 250, 500, 1000 and 2000 FTU/kg in various diets on the apparent total tract phosphorus excretion of weaned piglets (~9-40 kg). Results from the seven trials were combined and analysed to calculate total tract phosphorus excretion and phosphorus digestibility (see appendix: detailed trial design).

Total tract phosphorus digestibility was significantly (P<0.0001) improved with the addition of Axtra® PHY at all doses compared to the negative and positive control. The addition of Axtra® PHY at 2000 FTU/kg significantly (P<0.0001) improved phosphorus digestibility by 60.9% and 24.5% when compared to the negative and positive control respectively. Supplementing weaned piglet diets with Axtra® PHY at 250, 500 and 1000 FTU/kg significantly (P<0.0001) improved phosphorus digestibility by 39.7%, 43.2%, and 53.4% when compared to the negative control respectively. Supplementing weaned piglet diets with Axtra® PHY at 250, 500 and 1000 FTU/kg significantly (P<0.0001) improved phosphorus digestibility by 8.2%, 10.9%, and 18.8% when compared to the positive control respectively.

Total tract P excretion was significantly (P<0.0001) reduced with the addition of Axtra® PHY at all doses compared to the negative and positive control. The addition of Axtra® PHY at 2000 FTU/kg significantly (P<0.0001) reduced total tract phosphorus excretion by 51.6% and 53.5% when compared to the negative and positive control respectively. Supplementing weaned piglet diets with Axtra® PHY at 250, 500 and 1000 FTU/kg significantly (P<0.0001) reduced total tract phosphorus excretion by 34.0%, 38.1%, and 45.5% when compared to the negative control respectively. Supplementing weaned piglet diets with Axtra® PHY at 250, 500 and 1000 FTU/kg significantly (P<0.0001) reduced total tract phosphorus excretion by 36.6%, 40.6%, and 47.6% when compared to the positive control respectively.

Conclusion: Axtra® PHY at 250-2000 FTU/kg improves phosphorus digestibility and reduces total tract phosphorus excretion in weaned piglets (~9-40 kg), when fed various diet types, with the greatest reduction of phosphorus excretion at 2000 FTU/kg.

Comments

Axtra® PHY is a bacterial (*Buttiauxella sp.*) phytase expressed in *Trichoderma reesei.*

Keywords

Axtra® PHY, meta-analysis, phosphorus excretion, phosphorus digestibility, phytase, phytate, swine

References

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Detailed trial design

Seven individual trials were incorporated into a meta-analysis (see table below for summary of each trial). All seven trials measured total tract phosphorus excretion. In total, 380 weaned piglets (~9-40 kg) of different commercial breeds were randomly allocated to 6 dietary treatments (see table below). The negative control diet was fed either unsupplemented or supplemented with Axtra® PHY at 250, 500, 1000 or 2000 FTU/kg. The positive control was formulated to meet nutritional requirements compared to the NRC (2012) recommendation containing Ca in a range of 0.66-0.97% and digestible phosphorus in a range of 0.20-0.39%. The negative control diet was formulated to be reduced in digestible phosphorus (digestible phosphorus content in a range of 0.16-0.35%) and calcium (Ca content in a range of 0.49-0.65%). Diets were fed either as mash or pellets *ad libitum*. At the end of the trial faecal and urinary samples were collected and analysed for phosphorus. Total tract phosphorus excretion was then calculated. Phosphorus and calcium digestibility, retainable phosphorus and retainable calcium were also calculated.

Trial design:

Trial no.	Total pigs	Replicates/ treatment	Pigs/pen	Breed	Experimental phase (Overall)
1	48	8	1	Large White x Landrace	11- 18 kg
2	70	10	1	Great Yorkshire x Landrace	12-15 kg
3	54	9	1	PIG	10-15 kg
4	72	12	1	(Yorkshire x Landrace) x Duroc	20-40 kg
5	20	8	1	Talent x (Great Yorkshire x Landrace)	9-22 kg
6	20	8	1	Talent x (Great Yorkshire x Landrace)	9-22 kg
7	96	12	1	Landroc (Landrace cross Duroc)	11-20 kg

Diet used in trials:

Trial no.	Diet form	Diet	Axtra® PHY (FTU/kg)	Phytate phosphorus level
1	Pellet	Wheat/ SBM	250, 500, 1000, 2000	0.22
2	Pellet	Barley/ corn/ SBM	250, 500, 750, 1000, 2000	0.22
3	Mash	Corn/ SBM	250, 500, 1000, 2000	0.23
4	Mash	Corn/ SBM	250, 500, 1000, 2000	0.22
5	Mash	Wheat/ corn/ SBM	250, 500, 1000	0.22
6	Mash	Wheat/ corn/ SBM	250, 500, 1000	0.22
7	Mash	Corn/ SBM	500, 1000, 2000	0.23

Results: Summary of 7 trials in weaned piglets (9-40 kg BW)

	Positive control	Negative control (NC)	NC + 250 FTU/kg	NC + 500 FTU/kg	NC + 1000 FTU/kg	NC + 2000 FTU/kg
Total tract Phosphorus excretion (g/kg feed)	2.54^{a}	2.44^{a}	1.61^{b}	1.51^{bc}	1.33^{cd}	1.18^{d}
Phosphorus digestibility (%)	60.7^{d}	47.0^{e}	65.7^{c}	67.3^{bc}	72.1^{ab}	75.6^{a}
Retainable Phosphorus (% intake)	58.9^{d}	45.7^{e}	64.6^{c}	66.7^{bc}	70.7^{ab}	74.6^{a}
Calcium digestibility (%)	65.4^{b}	60.7^{c}	76.5^{a}	74.7^{a}	79.2^{a}	78.2^{a}
Retainable calcium (% intake)	60.3^{b}	48.0^{c}	64.7^{ab}	66.0^{ab}	69.8^{a}	73.2^{a}

^{abc} Values without a common superscript are significantly different ($P<0.05$)

Combination of 7 trials:
PB0804, PB0812, PB0819, PB0916_F, PB0921A, PB0921B, PB1006

Technical Report AxtraPHY.Meta.S.80

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文献 1

The addition of a *Buttiauxella* sp. phytase to lactating sow diets deficient in phosphorus and calcium reduces weight loss and improves nutrient digestibility

A. L. Wealleans,[1] R. M. Bold, Y. Dersjant-Li, and A. Awati

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ABSTRACT: Improving the efficiency of P use by pigs is especially important for lactating sows, whose metabolic requirements for P and Ca are high. The effect of a *Buttiauxella* sp. phytase on lactating sow performance and nutrient digestibility was investigated using the combined data set for 6 studies. Treatments included a nutritionally adequate positive control diet (PC), a negative control diet (NC; with an average reduction of 0.16% available phosphorous and 0.15% Ca vs. PC), and NC supplemented with a *Buttiauxella* sp. phytase at 250, 500, 1,000 or 2,000 phytase unit (FTU)/kg, respectively. Phosphorus and Ca deficiency in the NC resulted in significantly higher BW loss compared with the PC. All phytase treatments maintained BW loss at the same level as the PC. Increasing doses of phytase significantly ($P < 0.05$) reduced sow BW loss and increased energy intake, with improvements most apparent in sows older than parity 5. The positive effects on BW and energy intake were not observed in first-parity sows. This may be a consequence of fewer first parity sows in the data set. The apparent total tract digestibility of DM, OM, and CP were not affected by phytase supplementation. Digestible P and Ca were significantly improved (linear, $P < 0.0001$; quadratic, $P < 0.0001$) by increasing the dose of phytase supplementation. Significantly lower apparent total tract digestibility of energy, Ca, and P was found in the NC treatment vs. the PC treatment, whereas no significant differences were found between phytase treatment and the PC treatment. In conclusion, phytase supplementation at a level of 250 FTU/kg can replace 0.16% available phosphorous and 0.15% Ca; however, increasing the phytase dose can further reduce BW loss in sows fed P- and Ca- deficient diets.

Key words: digestibility, lactation, performance, phytase, sows

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INTRODUCTION

Weight loss in lactating animals is a direct consequence of the metabolic demands of milk production. This is especially high in sows, whose milk is nutritionally dense compared with other domesticated animals (Perrin, 1958; Jenness, 1982). Modern sows are required to nurse increasingly larger litters to be financially viable—the average litter size in France increased by 25% between 1986 and 2006 (Prunier et al., 2010)—creating a demand for nutrients that cannot be matched by the sow's relatively limited feed intake (Aherne and Williams, 1992; Clowes et al., 1998; Lawlor and Lynch, 2007). This differential between energy demand and intake leads to a state of catalysis and the mobilization of body reserves (McNamara, 1997). Phosphorus availability is complicated by the reduced bioavailability of organic P: about 60 to 80% of P in cereal grains is present in the form of phytate phosphorus (Maga, 1982). In this form, the P is largely inaccessible to pigs, which inherently do not possess enough of the enzymes required to hydrolyze the phytate into its component parts (Golovan et al., 2001). Accordingly, the utilization of P by pigs is poor: only between 20 and 40% of dietary P is metabolized without the aid of exogenous enzymes (Jongbloed et al., 2004). In approximately 70% of pig diets, this

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problem is solved by the addition of phytase: phytase in P-deficient diets will improve performance as well as reduce environmentally harmful levels of P in manure (Poulsen, 2000; Sands et al., 2001). However, as both Kemme et al. (1997b) and Jongbloed et al. (2004) noted, there is a paucity of literature on phytase efficacy in lactating sows, despite wide adoption of phytase in sow diets. Early work suggested that the optimum phytase dosage in sows was lower than for piglets and growing/finishing pigs, as more ideal conditions in the sow stomach allow for greater phytase efficacy (Kemme et al., 1997a), and subsequent studies have shown increases in P and Ca digestibility in sows fed P- and Ca-deficient diets, although there have been few demonstrated effects on sow or piglet performance (Lantzsch and Drochner, 1995; Jongbloed et al., 2004, 2013). The aim of this study was to evaluate the ability of a *Buttiauxella* sp. phytase to reverse losses in performance and digestibility caused by P and Ca deficiency in lactating sow diets.

MATERIALS AND METHODS

Experiments were conducted in accordance with all relevant institutional and national animal care guidelines at each participating experimental station.

Animal Trials

Six separate trials, as detailed in Table 1, were run to assess to efficacy of a *Buttiauxella* sp. phytase in P- and Ca-deficient diets for lactating sows. The following design criteria were used:

- The phytase must have been fed to lactating sows of known parity;
- The phytase must have been fed for entire study period, and the inclusion rates must have been available;
- Weight loss and feed intake must have been recorded;
- Nutrient digestibility for P and Ca must have been recorded;
- There must have been a negative and positive control treatment; and
- There must have been 2 or more replicates per treatment.

Individual sow data from the 6 separate trials were then collated in a database, providing 255 treatment means across 5 phytase inclusion levels (0, 250, 500, 1,000 or 2,000 FTU/kg. One FTU is defined as the quantity of enzyme that releases 1 μmol of inorganic P/min from 5.0 mM sodium phytate at pH 5.5 at 37°C. The phytase used in each study was a microbial 6-phytase from *Buttiauxella* sp. expressed in *Trichoderma reesei* (Danisco Animal Nutrition, Marlborough, UK). Within the study, information on the parity and diet was also recorded for each replicate used.

In each study, individual sows were the sampling unit and the experimental unit for digestibility and feed intake. Within each study, sows were randomly allocated to the dietary treatments and parity of the sows was balanced as much as possible.

Sow BW was recorded at farrowing and weaning. The BW of piglets were recorded at birth and weaning. The measurements of piglets within a litter were combined to provide information on litter birth weight, litter weaning weight, and litter weight gain until weaning. At farrowing, total number of pigs born, live born, and stillborn were recorded and cross-fostering of pigs was done to equalize litter size as much as possible; limitations on the extent of cross-fostering occurred when farrowing dates were disparate.

The experimental diets were provided ad libitum throughout lactation. Sows were fed treatment diets from Day 108 of gestation. To calculate ADFI, feed added and wastage (as detected) was recorded daily throughout the experimental period.

All sows and piglets were monitored daily for abnormalities and clinical signs of sickness as well as the availability of feed and water. Dead piglets, when they occurred, were recorded and piglet mortality was calculated by subtracting the number of piglets at the end of the experiment from the number of piglets at the beginning of the experiment. Mortality was expressed both as an absolute number and as a percentage.

All experimental diets were analyzed for marker, DM, Ca, and P. Available P was calculated using the slope ratio method (Soares, 1995). In each study, apparent total tract digestibilities of DM, OM, GE, N, fat, ash, NDF, Ca, and P were determined by the indirect method, using SiO_2 or TiO_2 as the marker and the concentration of Ti or Si in the calculations. The formula to calculate nutrient digestibility coefficients was

$$\text{DC nutrient} = [1 - (\text{nutrient/indicator})_{\text{feces}} / (\text{nutrient/indicator})_{\text{diet}}] \times 100\%,$$

in which DC is the digestibility coefficient of the nutrient (DC nutrient), $(\text{nutrient/indicator})_{\text{feces}}$ is the ratio of marker compound to nutrient in the feces, and $(\text{nutrient/indicator})_{\text{diet}}$ is the ratio of marker compound to nutrient in the feed.

Table 1. Trials used in this analysis

Trial	Country	Pigs per replicate	Number of replicates	Length of lactation	Dietary main grains[1]	Treatments used[2]	Analyzed phytase levels, FTU[3]/kg	Analyzed total P	Calculated AvP[4]	Analyzed total Ca
1	Netherlands	1	12	21	Maize/sunflower meal/RSM/SBM/ sugar beet pulp	PC	244	0.71	0.34	0.79
						NC	141	0.51	0.18	0.64
						250 FTU/kg	368	0.51	0.18	0.64
						2,000 FTU/kg	2,402	0.51	0.18	0.63
2	Netherlands	1	8	17	Maize/sunflower meal/RSM/SBM	PC	113	0.50	0.18	0.64
						NC	98	0.50	0.18	0.64
						250 FTU/kg	391	0.63	0.32	0.68
						500 FTU/kg	684	0.47	0.16	0.56
						1,000 FTU/kg	1,399	0.45	0.16	0.54
						2,000 FTU/kg	1,735	0.46	0.16	0.55
3	Canada	1	8	15	Wheat/barley/SBM	PC	252	0.45	0.16	0.55
						NC	256	0.45	0.16	0.53
						250 FTU/kg	447	0.45	0.16	0.52
						500 FTU/kg	603	0.60	0.35	0.81
						2,000 FTU/kg	1,746	0.44	0.19	0.66
4	United States	1	8	18	Maize/maize gluten meal/RSM/SBM	PC	<50	0.44	0.19	0.68
						NC	<50	0.45	0.19	0.66
						250 FTU/kg	347	0.44	0.19	0.67
						1,000 FTU/kg	1,632	0.64	0.35	1.03
						2,000 FTU/kg	2,747	0.45	0.16	0.78
5	Canada	1	8	15	Wheat/barley/SBM	PC	262	0.45	0.16	1.20
						NC	284	0.45	0.16	0.95
						250 FTU/kg	417	0.45	0.16	0.81
						500 FTU/kg	681	0.62	0.35	1.08
						2,000 FTU/kg	1,537	0.44	0.19	0.68
6	United States	1	13	15	Maize/SBM/DDGS	PC	57	0.45	0.19	0.72
						NC	56	0.45	0.19	0.69
						250 FTU/kg	355	0.44	0.19	0.68

[1]RSM = rapeseed meal; SBM = soybean meal; DDGS = dried distillers grains with solubles.

[2]PC = positive control diet; NC = negative control diet.

[3]FTU = phytase units.

[4]AvP = available phosphorous.

Statistics

Outlier removal was conducted using jackknife distances (Tukey, 1958; Miller, 1974): data rows where the jackknife distances for the multidimensional mean of improvements in body weight change, feed intake, and daily energy intake were more than 2.5 SD were excluded from the data set, resulting in the removal of 5 treatment rows: 2 removed rows came from the positive control diet (**PC**) treatment, 2 from the negative control diet (**NC**) treatment, and 1 from the 250 FTU/kg treatment.

The effect of length of lactation and main grain, as these variables differed between studies, on parameters of interest were analyzed using the REML method; trial was considered the random effect, as this accounts for the underlying heterogeneity between studies (Lean et al., 2009). Means separation was achieved using Tukey's honest significant difference test in the Fit Model platform of JMP 11 (SAS Inst. Inc., Cary, NC) and significance was determined at $P < 0.05$. Dietary main grain had no effect on performance parameters, DM digestibility, ash digestibility, digestible P, Ca, or energy. However, CP digestibility was significantly increased in wheat-based diets as compared with maize-based diets (88.91 vs. 85.83%; $P < 0.05$). Length of lactation was not significantly correlated with any digestibility or performance parameters. Therefore, the data from the 6 individual trials was combined into a single data set for further analysis.

For the effect of phytase, data were analyzed using the REML method; the model considered treatment as a main effect, parity was considered a covariate, and trial code was included as a random effect. Treatment means separation was achieved using Tukey's honest significant difference test in the Fit Model platform of

Table 2. Effect of supplementary phytase on lactating sow and piglet performance

Performance parameter	PC[1]	NC[1]	NC+250[1]	NC+500[1]	NC+1000[1]	NC+2000[1]	SEM	ANOVA	Linear	Quadratic
Weight after farrowing, kg	248.85	244.31	249.34	254.18	243.64	248.89	4.45	0.72	0.66	0.78
Weight after weaning, kg	233.42	219.97	230.95	235.75	222.21	230.22	6.20	0.23	0.12	0.37
BW change, kg	–16.05[a]	–24.66[b]	–19.68[ab]	–17.06[ab]	–16.94[ab]	–15.89[a]	6.55	<0.05	<0.05	0.18
BW change, %	–6.41[a]	–10.11[b]	–7.67[ab]	–6.49[ab]	–6.41[ab]	–6.36[a]	2.68	<0.05	<0.01	<0.1
Daily BW change, kg/d	–0.89[a]	–1.36[b]	–1.06[ab]	–0.93[ab]	–0.92[ab]	–0.86[ab]	0.18	<0.05	<0.05	0.26
Feed intake, kg/d	5.86	5.43	5.66	5.53	5.64	5.63	6.23	0.57	0.22	0.37
Daily energy intake, MJ	79.57	74.13	76.02	77.42	77.95	77.44	3.50	0.64	0.21	0.35
Piglets born	13.84	14.07	13.45	13.78	13.86	13.57	1.19	0.97	0.89	0.86
Born alive	12.74	12.78	12.10	13.15	13.23	12.60	1.17	0.83	0.57	0.75
Born dead	1.13	1.31	1.36	0.77	0.55	1.01	0.19	0.28	0.12	0.26
Average birth weight, kg	1.50	1.48	1.49	–[2]	1.43	1.48	0.13	0.97	0.60	0.74
Litter birth weight, kg	18.78	20.03	18.29	–	19.28	18.56	1.08	0.48	0.42	0.47
Preweaning deaths/litter	0.95	0.76	0.67	0.44	0.64	0.40	0.37	0.42	0.45	0.92
Preweaning deaths/litter, %	7.47	5.66	5.23	3.38	5.08	3.30	2.52	0.34	0.56	0.96
Piglets weaned/litter	10.72	11.16	10.80	10.73	10.64	11.16	0.41	0.30	0.14	0.42
Average weaning weight, kg	7.04	6.96	6.93	–	6.64	6.82	0.60	0.81	0.47	0.70
Litter weaning weight, kg	75.74	78.33	72.51	–	71.86	77.32	2.10	0.18	0.71	0.39

[a–c]Values within rows with the same superscript are not significantly different ($P < 0.05$).

[1]PC = positive control diet; NC = negative control diet; NC+250 = negative control + 250 FTU/kg; NC+500 = ; negative control + 500 FTU/kg; NC+1000 = negative control + 1,000 FTU/kg; NC+2000 = negative control + 2,000 FTU/kg.

[2]No data available for cells containing "–".

JMP 11 (SAS Inst. Inc.) and significance was determined at $P < 0.05$.

Data were split into "parity groups": primiparous sows ($n = 38$), sows on parity 2 through 4 ($n = 151$), and sows on parity 5 or above ($n = 67$). Performance parameters that were significantly affected in the overall data set were then investigated in each of these parity groups through REML analysis with trial as a random effect; Tukey's honest significant difference was used to separate treatment means. Significance was determined at $P < 0.05$.

RESULTS

The main effects of the level of *Buttiauxella* sp. phytase on sow and piglet growth performance are outlined in Table 2. Sow weight loss was negatively affected by the reduction of P and Ca in the diet, with NC sows losing 24.66 kg compared with 16.05 kg for PC sows ($P < 0.05$). Equivalence to the positive control was achieved at the lowest dose, 250 FTU, and a significant difference from the negative control was achieved at 2,000 FTU/kg ($P < 0.05$). There were no significant effects on piglet performance until weaning.

The data on sow BW change and feed intake were then split by parity group (first parity, parity 2–4, and parities 5+), as shown in Table 3. There were no significant differences between treatments in primiparous sows.

In midparity sows (parities 2, 3, and 4), there were significant linear relationships between phytase dose and all investigated parameters: BW change in kilograms and percent ($P < 0.001$), daily feed intake ($P < 0.05$), and daily energy intake ($P < 0.05$). Percent BW change also had significant quadratic effects ($P < 0.05$). The effect of phytase in maintaining body condition was greatest in older sows (parities 5+), reducing BW loss versus the negative control by 13.20, 13.89, 15.77, and 15.36 kg at 250, 500, 1,000, and 2,000 FTU/kg, respectively, with significant linear effects ($P < 0.05$).

The effect of supplementary phytase on nutrient digestibility is presented in Table 4. No differences were found between treatments for OM digestibility. Dry matter and CP digestibility were significantly affected by treatment: in both cases, the positive control reported the lowest digestibility coefficients (84.39 g/100 g DM and 86.15 g/100 g CP) and the 500 FTU/kg treatment reported the highest (86.81 g/100 g DM and 87.52 g/100 g CP). Phytase inclusion had no linear or quadratic effects on DM or CP digestibility.

Digestible P and Ca were significantly improved (linear, $P < 0.0001$; quadratic, $P < 0.0001$) by phytase supplementation. The reductions in dietary P and Ca led to significant rednctions in digestible P and Ca (0.07 g/100 g digestible P and 0.08 g/100 g digestible Ca) compared with the positive control. For digestible P, this reduction was reversed with the addition of 250 FTU/kg, with all levels of phytase supplementation

Table 3. Effect of supplementary phytase on lactating sow performance by parity

Performance parameter	PC[1]	NC[1]	NC+250[1]	NC+500[1]	NC+1000[1]	NC+2000[1]	SEM	ANOVA	Linear	Quadratic
Primiparous										
BW change, kg	–21.24	–20.83	–19.18	–[2]	–5.73	–14.12	6.12	0.46	0.43	0.14
BW change, %	–9.87	–9.60	–9.62	–	–2.92	–6.41	3.01	0.42	0.43	0.12
Feed intake, kg/d	4.84	5.22	5.14	–	7.10	5.66	0.56	0.18	0.16	0.29
Daily energy intake, MJ	66.24	72.56	71.47	–	98.83	78.61	13.4	0.16	0.16	0.29
Parities 2–4										
BW change, kg	–16.71^{ab}	–25.85^{b}	–21.38^{ab}	–15.76^{ab}	–12.17^{a}	–13.35^{a}	6.84	<0.01	<0.001	<0.1
BW change, %	–6.66^{ab}	–10.66^{b}	–8.64^{ab}	–5.81^{ab}	–4.57^{a}	–5.48^{a}	2.78	<0.01	<0.001	<0.05
Feed intake, kg/d	6.02^{a}	5.20^{b}	5.53^{ab}	5.39^{ab}	5.87^{ab}	5.63^{ab}	0.17	<0.05	<0.05	<0.1
Daily energy intake, MJ	82.27^{a}	71.21^{b}	75.40^{ab}	75.89^{ab}	80.81^{ab}	77.06^{ab}	3.04	<0.05	<0.05	<0.1
Parities 5+										
BW change, kg	–6.73^{a}	–32.00^{b}	–18.30^{ab}	–18.11^{ab}	–16.23^{ab}	–16.64^{a}	8.29	<0.05	<0.05	0.11
BW change, %	–2.07^{a}	–11.78^{b}	–6.77^{ab}	–6.53^{ab}	–5.36^{ab}	–5.74^{a}	3.01	<0.05	<0.05	0.13
Feed intake, kg/d	6.11	5.68	5.98	5.67	4.36	5.45	0.34	0.39	0.16	0.14
Daily energy intake, MJ	83.86^{a}	58.00^{b}	74.92^{ab}	79.04^{ab}	83.52^{ab}	76.07^{ab}	4.52	<0.05	<0.01	0.15

$^{a–c}$Values within rows with the same superscript are not significantly different ($P < 0.05$).

[1]PC = positive control diet; NC = negative control diet; NC+250 = negative control + 250 FTU/kg; NC+500 = ; negative control + 500 FTU/kg; NC+1000 = negative control + 1,000 FTU/kg; NC+2000 = negative control + 2,000 FTU/kg.

[2]No data available for cells containing "–".

providing significantly more digestible P than the NC. Digestible Ca was improved with the addition of all levels of phytase to within statistical insignificance of the positive control, with significant difference from the NC achieved at 500 FTU/kg. Digestible energy was also significantly improved by the addition of phytase (linear, $P < 0.0001$; quadratic, $P < 0.0001$), with each treatment releasing in excess of 0.5 MJ to the sow.

DISCUSSION

Body weight loss affects the sow's current lactation and also her future reproductive and piglet performance (Vesseur et al., 1994). Sows with excessive weight losses during lactation have extended remating intervals (Sterning et al., 1990; Zak et al., 1997, 1998), are less likely to return to estrus within 10 d of weaning, and have reduced ovulation rates (Zak et al., 1997) and reduced embryonic survivals (Close and Mullan, 1996).

Overall, the addition of *Buttiauxella* sp. phytase to sow diets significantly reduced both absolute ($P < 0.05$) and percent ($P < 0.01$) change in BW compared with the negative control. Equivalence to the positive control was achieved at the lowest dose, 250 FTU/kg, with further reductions with increasing dose. Nasir et al. (2014) reported that supplementation with an *Aspergillus oryzae* 6-phytase improved nutrient digestibility but not performance in lactating sows. This finding is echoed elsewhere in the literature, with Jongbloed et al. (2013) also finding no effect of phytase supplementation on sow BW change throughout lactation. This may suggest that the older generation phytases studied in previous papers were not able to release sufficient nutrients to impact weight loss, only recovering those removed from the NC. Previous studies with *Buttiauxella* sp. phytase in growing–finishing pigs have demonstrated dose-dependent improvements in energy, AA, nitrogen, and mineral digestibil-

Table 4. Changes in nutrient digestibility following phytase supplementation

Digestibility parameter	PC[1]	NC[1]	NC+250[1]	NC+500[1]	NC+1000[1]	NC+2000[1]	SEM	ANOVA	Linear	Quadratic
Ash, g/100g	45.57^{ab}	43.72^{b}	46.66^{ab}	47.74^{ab}	47.45^{ab}	48.71^{a}	11.36	<0.05	<0.001	<0.05
CP, g/100g	86.56^{b}	87.30^{a}	87.40^{a}	87.50^{a}	87.11^{ab}	86.65^{ab}	0.83	<0.01	0.06	0.08
DM, g/100g	84.39^{c}	86.38^{ab}	86.28^{ab}	86.29^{a}	86.09^{ab}	85.90^{b}	1.19	<0.0001	0.10	0.12
OM, g/100g	88.55	89.24	89.17	88.88	88.70	88.81	1.03	<0.1	0.59	0.66
DE, MJ	15.31^{a}	14.76^{b}	15.26^{a}	15.46^{a}	15.29^{a}	15.37^{a}	0.41	<0.001	<0.0001	<0.0001
Digestible Ca, g/100g	0.24^{ab}	0.16^{c}	0.20^{bc}	0.25^{ab}	0.27^{ab}	0.25^{a}	0.03	<0.0001	<0.0001	<0.0001
Digestible P, g/100g	0.20^{ab}	0.13^{c}	0.18^{b}	0.21^{ab}	0.22^{a}	0.22^{a}	0.01	<0.0001	<0.0001	<0.0001

$^{a–c}$Values within rows with the same superscript are not significantly different ($P < 0.05$).

[1]PC = positive control diet; NC = negative control diet; NC+250 = negative control + 250 FTU/kg; NC+500 = ; negative control + 500 FTU/kg; NC+1000 = negative control + 1,000 FTU/kg; NC+2000 = negative control + 2,000 FTU/kg.

ity over and above the expected improvements in P and Ca (Adedokun et al., 2015; Zeng et al., 2015), and this, combined with the differential pH optimum of *Buttiauxella* sp. phytase, which allows for nutrient release higher in the digestive tract (Menezes-Blackburn et al., 2015), will contribute to the reduction in weight loss demonstrated in this study.

Body weight losses can be especially detrimental to first parity sows, which are especially sensitive to body reserve depletion. In general, gilts are not physiologically mature at the time of first mating (Everts, 1994) and so do not have enough body reserves at first farrowing, and their feed intake capacity is not sufficient to fulfill energy needs during lactation (Mejia-Guadarrama et al., 2002). The results of this analysis did not show significant effects of phytase inclusion on weight loss in first parity sows, although a trend was observed for both absolute and relative BW change ($P < 0.1$). The nonsignificance of the data may be due to the low number of first parity animals ($n = 39$) compared with older animals ($n = 249$). In midparity sows (parities 2, 3, and 4), there were significant linear relationships between phytase dose and all investigated parameters: BW change in kilograms and percent ($P < 0.001$), daily feed intake ($P < 0.05$), and daily energy intake ($P < 0.05$). Percent BW change also had significant quadratic effects ($P < 0.05$).

The effect of phytase in maintaining body condition in P-deficient diets was greatest in older sows (parity 5+), reducing BW loss by 13.20, 13.89, 15.77, and 15.36 kg at 250, 500, 1,000, and 2,000 FTU/kg, respectively, with significant linear effects ($P < 0.05$). This is likely linked to the high BW loss of older sows on the NC (32.00 kg, 11.78%), suggesting that older sows are less capable of adapting to Ca- and P-deficient diets than younger sows.

Although higher parity sows can recycle and conceive with higher lactation weight losses compared with first-parity animals (Thaker and Bilkei, 2005), reduced weight losses in higher parity sows will reduce culling and replacement rate. Maintaining these indicators of reproductive performance will improve sow longevity, as culling rates increase with decreasing reproductive performance (Stalder et al., 2004; Sasaki and Koketsu, 2008), especially for young sows, where reproductive failure is the main reason for removal from the herd (Lucia et al., 2000). Increasing longevity will also reduce overall costs to the producer. Replacing sows at the end of their productive life incurs a financial cost: the difference in value between cull sows and replacement gilts is known as "livestock depreciation" and varies from herd to herd and between years.

Strategies to reduce lactating weight loss often involve increasing the fat and energy intake by sows (Eissen et al., 2003; Smits et al.., 2013). No significant differences in DM, OM, or CP digestibility were seen in this study, in line with the results of Jongbloed et al. (2004) and Kemme et al. (1997a,b).

No significant differences were seen in daily energy intake in the overall data set, but significant differences were seen in both mid-parity (parities 2–4) and older (parities 5+) sows. In both cases, energy intake was reduced in the NC treatment compared with the PC ($P < 0.05$), and the addition of phytase restored equivalence to the positive control ($P > 0.05$). However, a significant increase in energy digestibility was seen with all levels of supplementary phytase (Table 4; $P < 0.0001$). This, which supports the ability of the *Buttiauxella* sp. phytase to reduce BW loss, both in absolute and percentage terms, will likely improve sow reprodnctive performance, although no significant effects on piglet performance were seen in this study.

These results show that the *Buttiauxella* sp. phytase is effective at improving the digestibility of both P and Ca in lactating sows. Previous sow studies (Lantzsch and Drochner, 1995; Kemme et al., 1997a,b) using an *Aspergillus niger* phytase reported increased total tract digestibility of P, with no significant effects on Ca. Jongbloed et al. (2004) did find a significant effect of a *Peniophora lycii* phytase supplementation on Ca digestibility, although the authors attributed this to supplemental limestone in the NC. Unlike Jongbloed et al. (2004), the diets in the experiments investigated in this analysis did not try to balance the Ca:P ratios of the PC and NC; therefore, the improvement cannot be the result of supplemental limestone. Phytate is known to chelate with Ca and other trace minerals, reducing their bioavailability (Wise, 1983), and phytase-driven improvements in Ca digestibility are widely reported in younger pigs (Traylor et al., 2001; Braña et al., 2006; Rutherford et al., 2014).

Each study in this analysis used cross-fostering procedures, reducing the variation in litter size and piglet weight for each sow. However, piglet performance is often dependent on the level of sow health and nutrition before farrowing and in early lactation (Revell et al., 1998). As the *Buttiauxella* sp. phytase reduces weight loss and improves digestive capability, continuous supplementation of sow diets throughout the reproductive cycle may, therefore, be able to improve long-term indicators of sow and piglet performance, including pigs per sow/year, litters per sow/year, and kilograms of pig meat raised per sow/year.

In conclusion, this study shows that the addition of phytase to sow diets at 250 FTU/kg is able to replace 0.16% available P and 0.15% Ca in lactating sows diets, enabling producers to safely lower the level of Ca and P in sow diets. However, higher doses up to 2,000

FTU/kg will have further beneficial effects on BW loss, especially in older sows. The effects on younger sows and on subsequent reproductive parameters are not yet conclusively described and merit further attention.

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