Original article

Growth performance and nutrient utilisation as influenced in pigs by microbial phytase and vitamin E supplementation to a diet of high oxidative capacity

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Abstract – In the first of two experiments carried out with growing–finishing pigs, 40 barrows were kept from 25 to 104 kg body weight (BW). In the second experiment, 24 pigs were kept from 75 to 104 kg BW. The pigs were fed either a barley–maize-based diet (*C*), or the same diet supplemented with either 1 200 PTU phytase (*Ph*) or 200 mg α-tocopheryl acetate·kg^{-1} (*E*), or both (*PhE*) in order to assess the effect of microbial phytase and vitamin E on growth performance (experiment 1) and the precaecal digestibility of P, Ca, Mg, Fe, Cu, Zn, crude fat and fatty acids (experiment 2). *Ph* supplementation improved mean daily weight gain (*P* < 0.05) and reduced the feed conversion ratio (kg feed·kg^{-1} weight gain, *P* < 0.01). Supplementation with α-tocopherol (vitamin E) did not affect growth performance. *Ph* inclusion improved precaecal digestibility of P (*P* < 0.001) and reduced that of Zn (*P* < 0.05). The α-tocopherol addition improved (*P* < 0.01) the digestibility of Zn, whereas the α-tocopherol digestibility was not affected. The precaecal digestibility of total lipids and the saturated, monounsaturated and polyunsaturated fatty acids were reduced (*P* < 0.05 to 0.001) by *Ph* supplementation. The combined addition of *Ph* and *E* improved the digestibility of dietary fatty acids. We concluded that dietary phytase in pig diets susceptible to lipid oxidation demands an additional vitamin E supplementation in order to avoid detrimental effects on fat digestibility. (© Elsevier / Inra)

pigs / phytase / vitamin E / fatty acids / performance / digestibility

Résumé – Performances de croissance et utilisation des nutriments chez le porc sous l'influence de phytase microbienne et d'un supplément en vitamine E. Deux essais ont été réalisés avec des porcs en fin de croissance : dans le premier essai quarante porcs castrés ont été élevés de 25 à 104 kg de poids vif (PV) ; dans le second, vingt-quatre castrats de 75 à 104 kg de PV. L'alimentation des porcs consistait soit en une ration à base d'orge et de maïs (*C*), soit en la même ration supplémentée avec de la phytase à 1 200 U.P. (*Ph*) ou 200 mg d'acétate d'α-tocophérol (*E*) ou les deux (*PhE*), afin de

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déterminer les effets de la phytase microbienne et de la vitamine E sur les performances de croissance (essai 1), ainsi que sur la digestibilité précæcale du P, Ca, Mg, Fe, Cu, Zn, de la matière grasse et des acides gras (essai 2). Le gain journalier moyen à été plus élevé ($p < 0,05$) et l'indice de consommation a été plus faible ($p < 0,01$) pour les porcs nourris avec les régimes additionnés de phytase. La vitamine E (α-tocophérol) dans la ration n'a pas eu d'effet sur les performances de croissance. La digestibilité précæcale du P a été augmentée ($p < 0,001$) et celle du Zn réduite ($p < 0,05$) à la suite de l'incorporation de phytase. L'addition de vitamine E a augmenté la digestibilité du Zn, sans affecter la digestibilité de l'α-tocophérol. La digestibilité précæcale des matières grasses totales, des acides gras saturés, monosaturés et polyinsaturés a été réduite ($p < 0,05$ à $0,001$) par une supplémentation de phytase microbienne dans l'alimentation. L'addition combinée de vitamine E et de phytase (PhE) a augmenté la digestibilité des acides gras du régime alimentaire. L'inclusion de phytase dans la ration de porcs, dans le cas d'une ration susceptible à l'oxydation des lipides, nécessite donc l'addition de vitamine E supplémentaire, ceci afin d'éviter des effets négatifs sur la digestibilité des matières grasses. (© Elsevier / Inra)

porcs / phytase / vitamine E / acides gras / performances / digestibilité

1. INTRODUCTION

In numerous reports it is well documented that microbial-derived phytase in diets for pigs considerably increases the bioavailibility of various minerals and trace elements bound in the phytate complexes of dietary plant seeds [8, 17, 29]. The evidence for the nutritional significance and physiological and ecological importance of microbial phytase for monogastric animals has been given.

It is well known that free radicals, able to initiate lipid oxidation, can be formed in the presence of trace elements. For instance, free iron ions ($Fe^{2+/3+}$) are able to catalyse lipid peroxidation [24]. Nevertheless, there is only little information regarding whether minerals such as iron, copper and zinc hydrolysed from phytic acid complexes by exogenous phytase can influence the digestibility of nutrients that are very susceptible to oxidation as unsaturated fatty acids. Gebert et al. [8] found a significant reduction in the precaecal digestibility of total fat and particularly unsaturated fatty acids by inclusion of phytase in the diet. Furthermore, the digestibility of fatty acids was increased by the addition of α-tocopheryl acetate in diets supplemented with phytase. The results suggest some evidence that the inclusion of phytase in diets demands an additional supplementation of vitamin E (α-tocopherol) due to a higher oxidative load caused by an increased macro and micro mineral concentration in the digesta to avoid negative effects on fat digestibility.

The present study was aimed at testing the effects of vitamin E on feeding a diet very susceptible to lipid oxidation with and without microbial phytase on precaecal fatty acid modification and the absorption of these and of minerals as well as on the performance of growing pigs.

2. MATERIALS AND METHODS

2.1. Experimental design and animals

In experiments 1 and 2, respectively ten and six castrated male pigs (Large White), weighing approximately 26 and 75 kg, were randomly assigned to each of four treatments (*table I*). The pigs were housed individually and grown until 104 kg body weight (BW). They were fed either a control diet (*C*), or the same diet supplemented with either phytase (*Ph*) or vitamin E in the form of α-tocopheryl acetate (*E*), or both (*PhE*). All pigs had ad libitum access to their feed and water. Two pigs in experiment 1 (treatment *E*) were removed at 60 kg BW during the investigation

Table I. Dietary treatments and composition of the basal diet.

	Treatment			
	C	Ph	E	PhE
Supplements				
Phytase[1] (PTU·kg^{-1})	–	1 200	–	1 200
Vitamin E[2] (mg·kg^{-1})	–	–	200	200
Basal diet (%)				
Barley			33.0	
Maize			27.7	
Soybean meal (44 % crude protein)			11.0	
Sunflower meal (undehulled)			11.0	
Potato protein			5.2	
Safflower oil			7.3	
Lysine-HCl			0.2	
Ground limestone			1.6	
Salt			0.5	
Celite 545			1.5	
Vitamin-premix (based on maize)[3]			1.0	

[1] 240 mg Natuphos (≥ 5 000 PTU·g^{-1}) per kg from BASF, D - Ludwigshafen; [2] 400 mg Rovimix E - 50 SD (500 mg α-tocopheryl acetate·g^{-1}) per kg from F. Hoffmann - La Roche AG, CH - Basel; [3] per kg feed: vitamin B2, 4 mg; vitamin B6, 4 mg; vitamin A, 2 000 IU; vitamin D3, 500 IU; Ca-Pantothenate, 15 mg; Niacin, 20 mg; Ph × E means interaction of Ph and E.

because of sudden symptoms of oedema disease. Therefore, they were not included in the data analysis of growth performance.

2.2. Diets

The diets were cereal based, composed mainly of barley, maize, as well as extracted soybean meal, extracted sunflower meal and potato protein (table I). The intended susceptibility to lipid oxidation was obtained by using safflower oil as a fat source, high in unsaturated fatty acids with its low content of native α-tocopherol. Celite 545 (acid-washed diatomaceous earth), a nutritionally inert substance, was added to the diet to increase the level of 4N-HCl insoluble ash (AIA) and reduce variability in the analysis. The microbial phytase was oversupplemented by 20 % (table I), because the diets were steam-pelleted at 65 °C, and should contain a final concentration of 1 000 units (PTU)·kg^{-1}. The recommended total phosphorus concentration in diets for growing pigs is 0.3–0.4 g·MJ^{-1} digestible energy (DE) [21]. In the present investigation, no additional inorganic phosphorus was supplied to the diets,

because a low phosphorus content of less than 0.3 g·MJ^{-1} DE was desired. The added premix contained the essential vitamins on dietary recommended levels [21], as shown in table I, without vitamin E and supplemental trace elements.

As expected, the analysed nutrient, the mineral content and the fatty acid profile of the four diets were almost identical (table II). All diets contained the recommended levels of amino acids to allow good growth performance. The calculated content DE was 15.4 MJ·kg^{-1} DM. The diets were adequate in P, Mg, Fe and Cu, whereas the Ca content was rather high and the Zn content was below the recommendation for growing pigs [21]. Because of the relatively high quantity of safflower oil, the mean crude fat content exceeded 100 g·kg^{-1} DM, and the fatty acid profiles consisted of high values of unsaturated fatty acids, especially oleic and linoleic acid. The mean α-tocopherol content in treatment E and PhE was 250 mg·kg^{-1} DM, and the phytase activity of diet Ph and PhE was about 1 000 PTU·kg^{-1} DM. Both supplements corresponded to the estimated levels.

Table II. Analysed nutrient content, energy and mineral content and the fatty acid profile of the experimental diets.

	Treatment			
	C	Ph	E	PhE
Nutrient content per kg dry matter				
Crude ash, CA (g)	73	73	76	71
Crude protein, CP (g)	188	191	193	191
Crude fat, CL (g)	121	117	112	114
Crude fibre, CF (g)	65	62	65	60
Gross energy (MJ)	20.1	20.1	20.0	20.0
DE[1] (MJ)	15.3	15.4	15.3	15.5
α-tocopherol (mg)	54	57	243	258
Phytase activity (PTU)	< 150	1 025	< 150	1 003
Phosphorus (g)	3.9	4.3	4.2	4.3
Calcium (g)	9.5	9.3	9.1	8.3
Magnesium (g)	2.1	2.1	2.0	2.0
Iron (mg)	188	169	166	159
Copper (mg)	10	10	10	10
Zinc (mg)	44	36	36	41
Total fatty acids (g)	103	101	94	96
Fatty acid profile in % of total fatty acids [2]				
Σ SFA	12.9	12.8	12.8	12.9
$C_{16:0}$	9.6	9.5	9.5	9.6
$C_{18:0}$	2.8	2.8	2.7	2.7
Σ MUFA	20.9	20.3	20.7	20.8
$C_{18:1\ \omega\text{-}9}$	19.4	19.2	19.5	19.5
Σ PUFA	66.2	66.9	66.4	66.3
$C_{18:2\ \omega\text{-}6}$	64.5	65.2	64.8	64.7
$C_{18:3\ \omega\text{-}3}$	1.1	1.1	1.1	1.1

[1] Digestible energy, calculated from crude nutrients by regression: $DE = 19.0 * CP + 33.5 * CL - 21.2 * CF + 16.6 * NFE$; [2] SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; Σ = sum.

2.3. Sampling procedure

In experiment 1, the individual BW and feed intake data of the pigs were recorded weekly. The animals were slaughtered in the abattoir of the 'Prüfanstalt des Schweizerischen Verbandes für Mast- und Schlachtleistungsprüfung beim Schwein (MLP)'. Carcass dissection was assessed according to MLP regulations. The results were reported in another paper [9].

In order to collect samples of digesta from the intestinal tract, the animals from experiment 2 were slaughtered according to the method described by Hadorn [11]. Immediately after killing, digesta samples were taken from the caecum, frozen with liquid nitrogen and stored at −20 °C until the analytical procedure was performed.

2.4. Analytical methods

The caecal digesta samples were freeze-dried and ground in a centrifugal mill (Retsch ZM 1

Arlesheim, Switzerland) using a titan piston and titan sieve (0.5 mm). The standard *Weende* procedure was used to determine the nutrients in feed as dry matter (DM), crude ash (CA), crude fibre (CF) and crude protein (CP). Crude fat (CL) was analysed according to Winter [30]. The determination of the gross energy (GE) content was performed with an anisothermic calorimeter (IKA-Kalorimetersystem C 700 T, Heitersheim, Germany). The minerals P, Ca, Mg, Fe, Cu and Zn were analysed by atomic absorption spectrometry (Perkin Elmer AG Rotkreuz, Switzerland) at the Swiss Federal Research Station for Animal Production (RAP, Posieux, Switzerland) following the validated procedure [20, 22].

The α-tocopherol concentration was determined by the high performance liquid chromatography (HPLC) method of Rettenmaier and Schüep [23]. The lipid extraction was followed by the method of Winter [30] as modified by Prabucki [12] using chloroform/methanol (2:1, v/v). Prior to extraction, the digesta samples were adjusted to pH 2 by means of 37 % HCl. The extracted lipids were transformed to their methyl esters by using sodium hydroxide and boron trifluoride, both in methanol [15]. The fatty acid methyl esters (FAMEs) were analysed using a Hewlett Packard model HP 5860 A gas chromatograph, equipped with a flame ionisation detector (FID). The FAMEs were separated on a 30 m * 0.32 mm Supelcowax 10 CB fused-silica capillary column using the following time programme: 3 min at 175 °C, then to 230 °C with 3 °C·min^{-1}. The injector and detector temperature were maintained at 250 °C; the carrier gas was N$_2$. FAMEs were quantified by an external standard (C13:0).

The digestibility was estimated by means of the indicator method [19], using AIA as indicator.

2.5. Statistical analysis

Experimental data were analysed statistically by using Statgraphics plus for Windows version 2.1 [27] and treated by multifactor analysis of variance (ANOVA) with phytase and vitamin E level as factors. The results are given as means and standard deviations. When significant ($P < 0.05$) dependent variable effects were found, mean values were separated using Bonferroni's multiple range test (ns: not significant; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$).

3. RESULTS AND DISCUSSION

3.1. Effect of dietary treatments on growth performance

Under the experimental condition of ad libitum feeding, there was a significant influence of phytase supplementation on days in experiment, daily body weight gain (DWG) and feed conversion ratio (FCR) (*table III*). Daily feed intake (DFI) was not affected by *Ph* supplementation. The inclusion of dietary vitamin E to the diets did not significantly influence growth parameters. *Ph* pigs grew faster (73 g·day^{-1}), and the FCR was lower ($P < 0.01$) than in the pigs that received no phytase, because the days in experiment were also reduced ($P < 0.01$). As a consequence, the FCR was significantly lower for animals of treatments *Ph* and *PhE* than for those of treatment *E*. Since phytic acid is also able to form complexes with protein [10], an enhanced protein digestibility could be expected by the inclusion of phytase and therefore an expected influence on growth performance. In conclusion, the effectiveness of microbial phytase for pigs has been shown by the responses in performance.

The improvement in performance results of pigs due to phytase supplementation has been reported previously by Mroz et al. [16] and Cromwell et al. [4]. In their studies inclusion of dietary phytase up to 1 000 PTU·kg^{-1} feed in low phosphorus diets increased DFI and consequently improved DWG and decreased FCR.

In agreement with our results, no effect on growth parameters due to supplementation of diets with vitamin E has been reported in other investigations with growing pigs [3, 8, 14]. In contrast, Asghar et al. [1] reported a higher DWG and a better FCR in the early growth phase (first 4 weeks) of pigs fed a diet supplemented with α-tocopheryl acetate (100 and 200 mg·kg^{-1} feed). This controversy may be explained by Bieri et al. [2], who suggested that 200 mg vitamin E·kg^{-1} feed may be more than the optimal amount needed at those body weights

Table III. Effect of phytase and vitamin E supplementation on growth performance of pigs (experiment 1).

	Treatment			
	C	Ph	E	PhE
No. of pigs	10	10	8	10
Body weight start (kg)	26.0 (1.9)	25.8 (2.0)	25.9 (1.7)	25.9 (2.2)
Body weight end (kg)	103.6 (4.3)	104.0 (2.4)	103.4 (4.5)	102.9 (3.0)
Days in experiment (d)	112 (8)	103 (12)	117 (15)	104 (12)
Daily feed intake (kg)	2.07 (0.10)	2.12 (0.17)	2.08 (0.21)	2.12 (0.14)
Daily body weight gain (g)	697 (70)	768 (88)	676 (102)	749 (77)
Feed conversion ratio (kg·kg^{-1})	2.99^{ab} (0.23)	2.78^a (0.22)	3.12^b (0.31)	2.85^a (0.26)

Factorial means	Phytase		Vitamin E		P values		
	−	+	−	+	Ph	E	Ph × E
Body weight start (kg)	25.9	25.9	25.9	25.9	ns	ns	ns
Body weight end (kg)	103.6	103.6	103.9	103.9	ns	ns	ns
Days in experiment (d)	114	103	107	110	**	ns	ns
Daily feed intake (kg)	2.08	2.12	2.10	2.10	ns	ns	ns
Daily body weight gain (g)	686	759	732	712	*	ns	ns
Feed conversion ratio (kg·kg^{-1})	3.05	2.82	2.89	2.98	**	ns	ns

Mean values with different superscripts in a row are significantly different ($P < 0.05$).

and thus reduces the intestinal absorption of vitamin A, which he calls an important growth-promoting vitamin.

3.2. Effect of dietary treatments on precaecal mineral digestibility

The most pronounced effect ($P < 0.001$) of the supplementary phytase concerns the precaecal digestibility of phosphorus, which increased on average by 0.157 or 46 % (table IV). Surprisingly, the precaecal digestibility of zinc was reduced. However, the α-tocopherol supplementation had a positive effect on zinc digestibility. Calcium, magnesium, iron and copper digestibility was not affected by the Ph nor the E supplementation.

Negative values in digestibility, as obtained for copper in treatment Ph, can be explained by the exocrine secretion of gas-tric, biliary and pancreatic juices. Evaluating exogenous phytase efficacy over the total tract (faeces) digestibility, the phosphorus digestibility on factorial basis was 0.521 for the phytase-supplemented groups and 0.336 for the non-phytase-supplemented groups (data not shown) and were similar to the results in our recently completed study [8]. Evidently, in both studies, the precaecal digestibility of phosphorus indicated no significant difference from its faecal digestibility. These results coincide with those of Jongbloed et al. [13] and Mroz et al. [16], who by comparing faecal digestibility and the ileal digestibility, described that the net movement of total phosphorus into the large intestine was relatively small (up to 4.4 percentage units).

The values found for the precaecal digestibility of Ca, Mg, Fe, Cu and Zn were similar to our previous study (unpublished data) and were different from their faecal digestibilities. The results indicate that, in

Table IV. Treatment effects on precaecal digestibility of P, Ca, Mg, Fe, Cu and Zn (experiment 2).

	Treatment			
No. of pigs	C 6	Ph 6	E 6	PhE 6
Phosphorus	0.324[b] (0.046)	0.492[a] (0.077)	0.357[b] (0.086)	0.502[a] (0.097)
Calcium	0.385 (0.083)	0.324 (0.068)	0.320 (0.147)	0.370 (0.100)
Magnesium	0.350 (0.068)	0.233 (0.078)	0.294 (0.152)	0.305 (0.142)
Iron	0.158 (0.082)	0.115 (0.130)	0.152 (0.086)	0.142 (0.057)
Copper	0.127 (0.195)	−0.113 (0.236)	0.250 (0.483)	0.117 (0.376)
Zinc	0.468[ab] (0.085)	0.281[b] (0.101)	0.643[a] (0.194)	0.516[ab] (0.171)

Factorial means	Phytase		Vitamin E		P values		
	−	+	−	+	Ph	E	$Ph \times E$
Phosphorus	0.340	0.497	0.408	0.430	***	ns	ns
Calcium	0.352	0.347	0.354	0.344	ns	ns	ns
Magnesium	0.322	0.269	0.291	0.300	ns	ns	ns
Iron	0.155	0.128	0.137	0.147	ns	ns	ns
Copper	0.188	0.002	0.007	0.183	ns	ns	ns
Zinc	0.556	0.398	0.374	0.580	*	**	ns

Mean values with different superscripts in a row are significantly different ($P < 0.05$).

contrast to P, the digestibility of these minerals depends to a greater extent on the place of hydrolysis and/or absorption in the digestive tract. It was noted that endogenous excretion occurred as well. However, the degree of hydrolysis of the phytic acid complexes by Ph inclusion in different sections of the gastrointestinal tract of pigs has not yet been studied. Nevertheless, contradictory reports concerning intestinal absorption or excretion of some minerals were presented by Partridge [18], Drochner [6], Den Hartog et al. [5] and Rodehutscord et al. [25]. However, these disagreements probably emphasise the complexity of this subject.

3.3. Effect of dietary treatments on precaecal digestibility of α-tocopherol, fat and fatty acids

From the results presented in *table V*, there is evidence of a higher α-tocopherol concentration in the caecal digesta of pigs fed diets E and PhE than in pigs fed diets C and Ph. There was also a significant interaction between the two supplements. The digestibility of α-tocopherol was not affected by the dietary α-tocopherol level or phytase supplementation, respectively. The crude fat concentration in digesta and its digestibility were significantly influenced by Ph supplementation (*table V*). In treatment Ph, the caecal crude fat concentration was highest and the precaecal digestibility lowest, respectively, compared to the other treatments. We assumed that the liberation of anions by the microbial phytase resulted in a higher degree of saponification of the crude fat. Thus, an increased crude fat content in the caecal digesta of the Ph treatment group was observed. This observation is also concomitant with the decrease in the digestibility of Ca and Mg (*table IV*).

As previously reported [8], dietary α-tocopherol concentration did not alter the

Table V. Caecal concentration (per kg dry matter) of α-tocopherol and crude fat and digestibility in digesta (experiment 2).

No. of pigs	Treatment			
	C	Ph	E	PhE
	6	6	6	6
α-tocopherol				
Concentration (mg)	69[c] (20)	70[c] (20)	365[b] (126)	540[a] (130)
Digestibility	0.577 (0.128)	0.580 (0.105)	0.626 (0.142)	0.480 (0.133)
Crude fat				
Concentration (g)	60[b] (7)	92[a] (21)	69[b] (6)	73[ab] (12)
Digestibility	0.876[a] (0.017)	0.811[b] (0.036)	0.849[ab] (0.020)	0.844[ab] (0.027)

Factorial means	Phytase		Vitamin E		P values		
	−	+	−	+	Ph	E	Ph × E
α-tocopherol							
Concentration (mg)	217	305	70	452	*	***	*
Digestibility	0.602	0.530	0.578	0.553	ns	ns	ns
Crude fat							
Concentration (g)	64	83	76	71	**	ns	*
Digestibility	0.862	0.828	0.844	0.846	**	ns	*

Mean values with different superscripts in a row are significantly different ($P < 0.05$).

precaecal digestibility of α-tocopherol. Elmadfa and Bosse [7] reported that the range of vitamin E absorption is inversely proportional to the level of vitamin E in the feed, and the digestibility of vitamin E is strongly influenced by nutrients such as fatty acids. However, the results on α-tocopherol digestibility were comparable to those obtained by Schaarmann et al. [26] in pigs fed diets supplemented with vitamin E. The crude fat digestibility in the present study was higher than observed in our previous study due to a two-fold higher dietary concentration of the polyenic fatty acids in this study. It has long been known that many factors such as the mean chain length, degree of esterification or the ratio of saturated to unsaturated fatty acids influence the fat digestibility [28].

The precaecal digestibility of the fatty acids was significantly influenced by Ph supplementation (table VI). The lowest digestibility values were found for diet Ph and the highest for diet C ($P < 0.05$), respectively. Significant interactions between Ph and E occurred for total lipids, saturated and monoenic fatty acids. Total lipids are the sum of all chromatographically analysed fatty acids, whereas the crude fat (table V) was measured by weight analysis, and thus, explains the different values. The digestibility of the saturated and the monounsaturated fatty acids was significantly lower by 0.065 (8 %) and 0.074 (8 %), respectively, in diet Ph than in diet E. On tendency, similar results were obtained for the digestibility of the polyunsaturated fatty acids.

As expected, stearic acid ($C_{18:0}$) was digested at a lower rate than palmitic acid ($C_{16:0}$) due to its longer carbon chain. Overall, in treatment Ph the fatty acid digestibility was always the lowest and in treatment C

Table VI. Treatment effects on precaecal digestibility of fatty acids (experiment 2).

	Treatment			
No. of pigs	C 6	Ph 6	E 6	PhE 6
Σ Lipids	0.948[a] (0.010)	0.881[b] (0.041)	0.923[ab] (0.026)	0.916[ab] (0.015)
Σ SFA	0.898[a] (0.017)	0.760[c] (0.048)	0.825[b] (0.019)	0.815[bc] (0.046)
$C_{16:0}$	0.925[a] (0.012)	0.833[b] (0.061)	0.884[ab] (0.028)	0.883[ab] (0.020)
$C_{18:0}$	0.863[a] (0.039)	0.649[b] (0.066)	0.713[b] (0.053)	0.719[b] (0.102)
Σ MUFA	0.939[a] (0.011)	0.828[b] (0.058)	0.902[a] (0.039)	0.894[a] (0.021)
$C_{18:1\ \omega\text{-}9}$	0.943[a] (0.010)	0.841[b] (0.059)	0.909[a] (0.038)	0.901[ab] (0.020)
Σ PUFA	0.960[a] (0.008)	0.927[b] (0.025)	0.947[ab] (0.024)	0.941[ab] (0.011)
$C_{18:2\ \omega\text{-}6}$	0.963[a] (0.008)	0.931[b] (0.025)	0.951[ab] (0.023)	0.945[ab] (0.011)
$C_{18:3\ \omega\text{-}3}$	0.931 (0.006)	0.910 (0.013)	0.926 (0.018)	0.920 (0.015)

Factorial means	Phytase		Vitamin E		P values		
	$-$	$+$	$-$	$+$	Ph	E	$Ph \times E$
Σ Lipids	0.936	0.898	0.915	0.919	**	ns	*
Σ SFA	0.861	0.787	0.829	0.820	***	ns	***
$C_{16:0}$	0.905	0.858	0.879	0.883	**	ns	**
$C_{18:0}$	0.788	0.684	0.756	0.716	**	ns	**
Σ MUFA	0.921	0.861	0.884	0.898	***	ns	**
$C_{18:1\ \omega\text{-}9}$	0.926	0.871	0.892	0.905	**	ns	**
Σ PUFA	0.954	0.934	0.944	0.944	*	ns	ns
$C_{18:2\ \omega\text{-}6}$	0.957	0.938	0.945	0.948	*	ns	ns
$C_{18:3\ \omega\text{-}3}$	0.928	0.915	0.920	0.923	*	ns	ns

SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; Σ = sum. Mean values with different superscripts in a row are significantly different ($P < 0.05$).

and E the highest, whereas treatment PhE was in between, thus confirming recent data [9]. In the present study the effects were more pronounced as a consequence of the high dietary amount of unsaturated fatty acids and therefore those of higher susceptibility to lipid oxidation. The results indicate that the digestibility of the saturated as well as the unsaturated fatty acids was significantly affected by the phytase supplementation. We suggest that unsaturated fatty acids of the diet Ph might be oxidised by hydrolysed trace elements from phytic acid complexes or from formed free radicals due to the dietary Ph inclusion. This is largely due to the fact that the rate of lipid oxidation is mainly related to the polyenic fatty acids in the feed. On the other hand, the present results on fatty acid digestibility show elevated digestibilities in treatment PhE compared to treatment Ph. One can assume that the supplemented vitamin E was used as an antioxidant to prevent the susceptible compounds such as unsaturated fatty acids in the diet from oxidation in the digestive tract.

4. IMPLICATIONS

The commercially available phytase used in this study was effective in improving the performance results of growing–finishing

pigs fed diets not supplemented with inorganic phosphorus as well as other macro and micro minerals. This result was brought about by a considerable increase in phosphorus digestibility of the diet. An extra dietary supplementation with α-tocopheryl acetate may be recommended in pig diets with microbial phytase inclusion and with a high fatty acid oxidative capacity.

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