Oregano oil and multi-component carbohydrases as alternatives to antimicrobials in nursery diets

Darryl Ragland, DVM, PhD; Deborah Stevenson, RVT; Michael A. Hill, BVetMed, MS, PhD

Summary

Objective: To evaluate the growth-promoting potential of oregano oil and multi-component carbohydrases individually and in combination.

Materials and methods: One hundred eighty 21-day-old Yorkshire-Landrace pigs were randomly assigned to five treatments. Treatments were the unsupplemented, unmedicated basal diet (Control) and the basal diet supplemented with either 4.41 g per tonne flavomycin (Huvepharma, Inc, Peachtree City, Georgia; Flavomycin), 1.5 kg per tonne oregano oil (Van Beek Scientific, Orange City, Iowa; Oregano), 50.1 g per tonne multi-component carbohydrase (Van Beek Scientific; Carbohydrase), or a combination of 750 g per tonne oregano oil and 50.1 g per tonne carbohydrase (Oregano oil-carbohydrase).

Results: Pigs fed the Flavomycin diet achieved the highest ($P < .05$) final bodyweights, average daily gain, and average daily feed intake (ADFI). Pigs fed the Oregano oil-carbohydrase diet exhibited better feed efficiency than pigs fed the Control, Flavomycin, and Oregano diets ($P < .05$). Average daily gain of pigs fed the Control diet and Carbohydrase and Oregano oil-carbohydrase diets did not differ ($P > .05$). Pigs fed the Control diet had higher ADFI than pigs fed the Oregano, Carbohydrase, or Oregano oil-carbohydrase diets ($P < .05$).

Implications: Under the conditions of this study, oregano oil and multi-component carbohydrases, fed individually or in combination, are inferior to flavomycin as growth-promoting supplements for nursery pigs. diets ($P < .05$).

Keywords: swine, nursery, oregano oil, multi-component carbohydrases, flavomycin

Received: August 8, 2007
Accepted: April 7, 2008

Resumen - Aceite de orégano y carbohidrasas de componentes múltiples como alternativas de los antimicrobianos en dietas de destete

Objetivo: Evaluar el potencial como promotor de crecimiento del aceite de orégano y de las carbohidrasas de componentes múltiples ofrecidos individualmente y en combinación.

Materiales y métodos: Ciento ochenta cerdos Yorkshire-Landrace de 21 días de edad se asignaron al azar a cinco tratamientos. Los tratamientos fueron la dieta base no medicada, no suplementada (Control) y la dieta base suplementada con 4.41 g por tonelada de flavomicina (Huvepharma, Inc, Peachtree City, Georgia; Flavomycin), 1.5 kg por tonelada de aceite de orégano (Van Beek Scientific, Orange City, Iowa; Orégano), 50.1 g por tonelada de carbohidrasas de componentes múltiples (Van Beek Scientific; Carbohydrase), o una combinación de 750 g por tonelada de aceite de orégano y 50.1 g por tonelada de carbohidrasas (Aceite de orégano-carbohidrasas).

Resultados: Los cerdos alimentados con la dieta de Flavomicina lograron los pesos corporales finales, ganancia diaria promedio, y consumo de alimento diario promedio (ADFI por sus siglas en inglés) más altos ($P < .05$). Los cerdos alimentados con la dieta de Aceite de orégano-carbohidrasas exhibieron una mejor eficiencia alimenticia que los cerdos alimentados con las dietas Control, Flavomicina, y Orégano ($P < .05$). La ganancia diaria promedio de los cerdos alimentados con la dieta Control y las dietas de carbohidrasas y Aceite de orégano-carbohidrasas no difirieron ($P > .05$). Los cerdos alimentados con la dieta Control tuvieron un ADFI más alto que los cerdos alimentados con las dietas de Orégano, Carbohidrasas, o Aceite de orégano-carbohidrasas ($P < .05$).

Implicaciones: Bajo las condiciones de este estudio, las carbohidrasas de componentes múltiples y el aceite de orégano, ofrecidos en alimento de manera individual o en combinación, son inferiores a la flavomicina como suplementos de promoción de crecimiento en cerdos en destete.

Résumé - Huile d'origan et glycosidases multi-composantes comme alternatives aux antimicrobiens dans la diète dans les pouponnières

Objectif: Évaluer le potentiel de l'huile d'origan et des glycosidases multi-composantes utilisé seul ou en combinaison comme promoteur de croissance.

Matériels et méthodes: Cent quatre-vingt porcelets Yorkshire-Landrace âgées de 21 jours ont été répartis de manière aléatoire à cinq groupes de traitement. Les traitements étaient la ration de base non-supplémentée et sans médicament (groupe Témoin), la ration de base supplémentée avec soit 4.41 g par tonne de flavomycine (Huvepharma, Inc, Peachtree City, Georgie; Flavomycin), 1.5 kg par tonne d'huile d'origan (Van Beek Scientific, Orange City, Iowa; Origan), 50.1 g par tonne de glycosidases multi-composantes (Van Beek Scientific; Glycosidase), ou une combinaison de 750 g par tonne d'huile

Department of Veterinary Clinical Sciences, Purdue University School of Veterinary Medicine, West Lafayette, Indiana.

Corresponding author: Dr Darryl Ragland, Purdue University, VCS/LYNN, 625 Harrison Street, West Lafayette, IN 47907-2026; Tel: 765-494-1209; Fax: 765-496-2608; E-mail: raglandd@purdue.edu.

This article is available online at http://www.aasv.org/shap.html.

Ragland D, Stevenson D, Hill MA. Oregano oil and multi-component carbohydrases as alternatives to antimicrobials in nursery diets. *J Swine Health Prod.* 2008;16(5):238–243.

d'origan et 50.1 g par tonne de glycosidase (Huile d'origan-glycosidase).

Résultats: Les porcs nourris avec la ration Flavomycin ont obtenu les valeurs les plus élevées ($P < .05$) pour le poids corporel final, le gain moyen quotidien, et la consommation moyenne quotidienne (ADFI). Les porcs nourris avec la ration Huile d'origan-glycosidase ont montré une meilleure efficacité alimentaire que les porcs nourris avec les rations Témoin, Flavomycin, et Origan ($P < .05$). Le gain moyen quotidien des porcs nourris avec les rations Témoins, Glycosidase, et Huile d'origan-glycosidase n'étaient pas différents ($P > .05$). Les animaux nourris avec la ration Témoin avaient un ADFI supérieur à celui des porcs nourris avec les rations Origan, Glycosidase, ou Huile d'origan-glycosidase ($P < .05$).

Implications: Dans les conditions expérimentales de la présente étude, l'huile d'origan et les glycosidases multi-composantes, administré individuellement ou en combinaison, sont inférieurs à la flavomycine à titre de promoteur de croissance pour les porcs en pouponnière.

The use of subtherapeutic antimicrobials to improve growth and feed efficiency of food-producing animals has been an integral part of livestock production in the United States for almost 60 years.[1] Use of antimicrobials in this manner is being contested on the basis that it has impaired the efficacy of antimicrobials used in the treatment of human infectious diseases.[2] The perception that restricting antimicrobial use promotes a decrease in the level of resistance of microorganisms obtained from livestock is supported by published literature. Investigators in the United States determined that total elimination of antimicrobials from the swine production environment promoted a decrease in the level of antimicrobial resistance measured in *Escherichia coli*.[3] Moreover, legislation in Denmark that mandated cessation of subtherapeutic antimicrobial use appears to have precipitated a decrease in antimicrobial resistance measured in fecal enterococci from pigs.[4] However, the noteworthy consequence of restrictions on subtherapeutic antimicrobial use in Denmark was a marked increase in clinical disease in the production environment and a marked increase in the amounts of therapeutic antimicrobials required to treat these infectious processes.[5] Therefore, restrictions on subtherapeutic antimicrobial use may exert an undesirable effect on animal health. Technological advances have enabled development of an extensive assortment of products and compounds that have been proposed as alternatives to subtherapeutic antimicrobials.[6] Plant-based phytochemicals and enzymatic preparations are two categories of products that are viewed as potential replacements for subtherapeutic antimicrobials in swine diets. Oregano oil is an aromatic extract from the leaves of *Origanum vulgare* and contains the antimicrobial compounds carvacrol and thymol, which are purported to behave similarly to antimicrobials by disrupting the cell walls of bacteria.[7]

Published results from growth and feed-utilization studies with nursery pigs have been scarce, and the data that is emerging has been mixed as it pertains to the viability of oregano oil as a growth promoter for pigs.[8,9] Supplemental enzyme technology dates back to the 1920s and grew in popularity in the 1980s, primarily because of work by digestive physiologists to characterize enzyme substrate activity, coupled with improvements in efficiency of enzyme production.[10] The most notable supplemental enzyme is phytase, which has assumed a place of importance in swine nutrition programs because of efforts to improve bioavailability of phosphorus and reduce its excretion in manure.[11] Other enzymatic preparations generating considerable interest in monogastric nutrition programs include multi-component enzyme formulations with the ability to degrade complex and structural carbohydrates that are indigestible in monogastric species. Investigators have documented favorable responses in pig growth and nutrient availability when nursery-pig diets were supplemented with multi-component carbohydrases.[12,13] The objective of the study described herein was to evaluate the growth-promoting potential of oregano oil and multi-component carbohydrases individually and in combination.

Materials and methods

Experimental design

A 42-day growth assay was used to evaluate the effect of oregano oil and multi-component carbohydrases on pig growth and feed utilization. On entering the nursery at 21 days of age (Day 0), 180 crossbred pigs were assigned to dietary treatments, with equal numbers of barrows and gilts. The experiment consisted of a randomized complete block design with a total of six replicate blocks. Each of the five dietary treatments used in the experiment was assigned to six pens, with pen the experimental unit. Pigs were weighed weekly and a feed record was maintained to monitor feed additions. Feed consumption was determined by obtaining feeder weights on Day 21 (when the change was made from Phase One to Phase Two diets) and on Day 42 (when the study was terminated).

Pigs and housing

The pigs were farrowed at the Purdue University Animal Sciences Research and Education Center (West Lafayette, Indiana) and the study was completed in the conventional on-site nursery. Average bodyweight was 5.9 kg (SE, 0.01) on Day 0. The nursery was environmentally controlled, pens were 1.98 m^2, the flooring was plastic-coated wire, and six pigs were housed in each pen. The study was reviewed and approved by the Purdue University Animal Care and Use Committee.

Diets

The basal diet (Control) consisted of an unsupplemented, unmedicated nursery formulation representative of standard nursery diet formulations used by the Purdue University Animal Sciences Research and Education Center Swine Unit (Table 1). The basal diet met or exceeded National Research Council recommendations for nursery pigs of this age.[14] The basal diet was supplemented with either Flavomycin 4 (Huvepharma, Inc, Peachtree City, Georgia; 4 g bambermycins per lb of premix) at a concentration of 4.41 g per tonne (Flavomycin diet); or Royal Nutrizyme (Van Beek Scientific, Orange City, Iowa), a powdered oregano oil product, at a concentration of 1.5 kg per tonne (Oregano diet); or Zympex 008 (Van Beek Scientific), a powdered multi-component carbohydrase, at a concentration of 50.1 g per tonne (Carbohydrase diet); or Royal Nutrizyme and Zympex 008 in combination (Oregano oil-carbohydrase diet) at a concentration of 750 g per tonne and 50.1 g per tonne, respectively. The concentrated (10×) form of Zympex 008 was used to formulate the diets containing carbohydrase. Zympex 008 is described as possessing the following enzymatic affinities: α-galactosidase, β-mannanase, protease, amylase, β-glucanase, xylanase, and cellulase. Royal Nutrizyme contains 75 g oregano oil per kg of product and utilizes calcium carbonate as its primary

Table 1: Basal diet composition for nursery pigs in a study evaluating the growth-promoting potential of oregano oil and multi-component carbohydrases individually and in combination*

Ingredients (kg/tonne)	Phase One basal diet	Phase Two basal diet
Corn	519.99	640.63
Soybean meal	280.56	320.64
Dicalcium phosphate	5.01	11.02
Limestone	6.61	8.82
Salt	2.51	3.51
Soybean oil	20.04	NA
Animal fat†	NA	10.02
Lysine HCl‡	1.70	2.10
Swine vitamin premix§	2.51	2.51
Swine TM premix¶	1.25	1.25
Selenium 600 premix**	0.50	0.50
Dried whey	110.22	NA
Select menhaden fish meal	50.10	NA
Phytase††	1.00	1.00
Calculated nutrient composition		
Digestible energy (kcal/kg)	3.6	3.5
Crude protein (%)	22.0	20.5
Lysine (%)	1.45	1.3

* Pigs entered the nursery on Day 0 (mean body weight 5.9 ± 0.01 kg). Phase One diets were fed Days 0 to 20, and Phase Two diets Days 21 to 42.

† Choice white grease.

‡ Lysine HCl; 78.5% L-lysine.

§ Supplied per kg of complete diet Days 0-20: vitamin A, 6105 IU; vitamin D, 611 IU; vitamin E, 44 IU; vitamin B_{12}, 40 µg; menadione, 2.0 mg; riboflavin, 7.2 mg; d-pantothenic acid, 22.2 mg; niacin, 44 mg. Supplied per kg of complete diet Days 21-42: vitamin A, 5990 IU; vitamin D, 599 IU; vitamin E, 43.6 IU; vitamin B_{12}, 30 µg; menadione, 2.0 mg; riboflavin, 7.0 mg; d-pantothenic acid, 21.8 mg; niacin, 43.6 mg.

¶ Supplied per kg of complete diet Days 0-20: copper, 11.2 mg; iodine, 0.42 mg; iron, 120 mg; manganese, 14.9 mg; zinc, 120 mg. Supplied per kg of complete diet Days 21-42: copper, 11.4 mg; iodine, 0.42 mg; iron, 122.6 mg; manganese, 15.2 mg; zinc, 122.6 mg.

** Selenium, 0.301 g/tonne.

†† Natuphos 600 (BASF Animal Nutrition, Florham Park, New Jersey), 600 FTU phytase/g.

NA = not applicable.

digestible carrier. The diets supplemented with flavomycin were assayed by Eurofins Scientific Inc (Memphis, Tennessee) to determine the amount of flavomycin per tonne of complete feed.

Statistical analysis

Pen served as the unit of analysis, and least squares (LS) means for body weight, average daily gain (ADG), average daily feed intake (ADFI), and feed:gain (F:G) were calculated and subjected to an unbalanced ANOVA using the GLM procedure of SAS (SAS Institute, Cary, North Carolina,). The least significant difference test was used as the mean separation procedure. A P value of < .05 was considered significant.

Results

Assay of the Flavomycin diets determined that the Phase One diet contained 3.31 g per tonne flavomycin and the Phase Two diet contained 3.90 g per tonne flavomycin. The LS means for body weight, ADG, ADFI, and F:G data are listed in Table 2. Pigs fed the Flavomycin diet had the heaviest body weights at the end of the study, achieved the greatest ADG, and consumed the greatest amounts of feed ($P < .05$). Pigs fed the Oregano oil-carbohydrase diet exhibited better feed efficiency ($P < .05$) than pigs fed the Control, Flavomycin, and Oregano diets. Pigs fed the Control diet achieved heavier body weights and higher ADFI than pigs fed the Oregano, Carbohydrase, or Oregano oil-carbohydrase diets ($P < .05$). Average daily gain of pigs fed the Control diet did not differ ($P > .05$) from that of pigs fed the Carbohydrase and Oregano oil-carbohydrase diets. Feed efficiency of pigs fed the Flavomycin diet did not differ ($P > .05$) from that of pigs fed the Control diet and the diets supplemented with oregano oil and carbohydrase individually. Pigs fed the diet containing carbohydrase had higher ($P < .05$) final body weights, ADG, and ADFI than pigs fed the diet supplemented with oregano oil. The treatment combining oregano oil and carbohydrase resulted in final body weights, ADG, and F:G that did not differ ($P > .05$) from those observed in pigs supplemented with carbohydrase alone. No difference

Table 2: Least squares means for body weight, average daily gain (ADG), average daily feed intake (ADFI), and feed:gain (F:G) of nursery pigs fed diets containing flavomycin, oregano oil, carbohydrases, oregano oil-carbohydrases in combination, or the unsupplemented base diet (Days 0-42)*

Variable	Control	Flavomycin†	Oregano oil‡	Carbohydrases§	Oregano oil-carbohydrases¶	SE
Body weight Day 0 (kg)	5.9	5.9	5.9	5.9	5.9	0.01
Body weight Day 42 (kg)	17.6[a]	18.2[b]	16.8[c]	17.3[d]	17.2[d]	0.24
ADG (g/day)	277.9[ab]	293.9[c]	258.9[d]	272.7[a]	268.7[a]	5.76
ADFI (g/day)	506.9[a]	538.4[b]	470.9[c]	490.3[d]	475.7[c]	11.9
F:G (kg/kg)	1.83[a]	1.84[a]	1.82[a]	1.81[ab]	1.78[b]	0.03
Pigs per treatment**	36	36	36	36	36	NA
Pigs per pen**	6	6	6	6	6	NA
Pens per treatment	6	6	6	6	6	NA

* Pigs approximately 21 days of age at weaning (Day 0). Control (basal) diets described in Table 1. Supplements were added to the basal diets at the expense of corn.

† Flavomycin 4 (Huvepharma, Inc, Peachtree City, Georgia) added to the basal diet at 4.41 g/tonne.

‡ Powdered oregano oil product (Royal Nutrizyme; Van Beek Scientific, Orange City, Iowa) added to the basal diet at 1.5 kg/ tonne.

§ Zympex 008 (Van Beek Scientific) added to the basal diet at 50.1 g/tonne.

¶ Royal Nutrizyme and Zympex 008 added to the basal diet at 750 and 50.1 g/tonne, respectively.

** During the study, two pigs from the Control, two pigs from the flavomycin, three pigs from the carbohydrase, and one pig from the oregano oil-carbohydrase treatments were removed from the study for antimicrobial therapy due to infectious arthritis-synovitis, presumed *Streptococcus suis* infection, or both.

[abcd] Values within a row with different superscripts differ ($P < .05$; unbalanced ANOVA). The pen was the experimental unit.

SE = standard error; NA = not applicable.

($P > .05$) in ADFI was observed for pigs supplemented with oregano oil alone or with oregano oil-carbohydrase.

During the study, two pigs from the flavomycin treatment, three pigs from the carbohydrase treatment, two pigs from the control treatment, and one pig from the oregano oil-carbohydrase treatment were removed from the study for antimicrobial therapy due to infectious arthritis-synovitis, presumed *Streptococcus suis* infection, or both.

Discussion

Greater utilization of feed additives described as alternatives to subtherapeutic antimicrobials may become necessary if proposed legislation restricting antimicrobial growth promotion gains approval in the United States.[15] Complete restriction of antimicrobial growth promotion would satisfy some in the human health field; however, the impact on animal health, animal production, and the economics of production could present greater challenges to the livestock industry.[5] Products containing oregano oil have been in development for several years, and interest in these products as antimicrobial alternatives continues to grow.[16] Oregano oil is believed to exert its effect by improving palatability and promoting greater feed intake. Oregano is a member of the mint family and imparts a lasting odor to feed. The number of published studies evaluating oregano oil supplementation in nursery-age pigs has been limited, but more information is emerging.[8,9] Several published studies[17-19] have evaluated the benefit of feeding oregano oil to sows, and the results have been encouraging on the basis of improvements in sow mortality, culling rate, farrowing rate, liveborn piglets per litter, and feed intake. The results of the current study agree with those described by other investigators[20] and with work conducted by our group,[21] in which oregano-oil supplementation failed to promote improvements in pig growth or feed utilization. The modest response in ADG by pigs fed the diet containing oregano oil appears to be due in part to markedly lower ADFI than that observed in the Control, Flavomycin, and Carbohydrase treatments. Another factor that merits consideration is interspecies variation of *O vulgare* as it pertains to the potential impact on carvacrol and thymol content in the extracted oil. Carvacrol and thymol are the active compounds in oregano essential oil and are described as possessing antimicrobial properties.[7] Regional differences in cultivars may influence levels of these compounds and potentially influence the magnitude of growth and feed utilization responses to diet supplementation.

Supplemental enzymes represent a class of feed additives that have grown in importance because of their observed capacity to positively influence nutrient availability and significantly reduce nutrient excretion into the environment.[11] Carbohydrate enzymes function by attacking and degrading β-1,3 and β-1,4 linkages of complex carbohydrates like arabinoxylans and glucans in cereal grains and oilseed meals.[22] Monogastric animals do not secrete these enzymes and are unable to utilize more complex sugars in some cereal grains. A pertinent example of how carbohydrases function is the effect of glucanase on β-glucan residues in barley and oats. β-glucans cause increased viscosity of intestinal contents in poultry and result in "sticky droppings" which impair carcass and egg quality.[23] The literature appears to support the theory that dietary supplementation with enzymes that possess an affinity for carbohydrate moieties improves pig performance.[12,13,24,25]

In the current study, supplementation with multi-component carbohydrases resulted in higher final body weight, ADG, and ADFI in treated pigs than in pigs fed the diet supplemented with oregano oil. The lack of a greater response in pig performance to enzyme supplementation was most likely due to the fact that corn-soy diets do not contain significantly high amounts of non-starch polysaccharides, compared to cereals like barley, oats, wheat, and rye. Therefore, the amount of available substrate may have been limiting due to composition of the diet, effectively restricting the activity of the enzyme. Supplementing the basal diet with oregano oil-carbohydrase resulted in higher final body weight and ADG than that in pigs fed the diet supplemented with oregano oil alone. The oregano oil-carbohydrase combination also supported a lower F:G than did the Control diet and the diets supplemented with either flavomycin or oregano oil. The possibility of a synergistic effect between oregano oil and carbohydrase must be considered in the observed feed-utilization response, because final body weight and ADG were lower in pigs fed oregano oil alone. Response to enzyme supplementation is often variable and frequently depends on the enzyme formulation, its substrate affinities, and presence of the specific substrates in the diet.

Reduced reliance on antimicrobials in swine nutrition programs is strongly advocated, but the bambermycin class of antimicrobials may represent part of the solution to the antibiotic resistance dilemma. Evidence has existed for more than 30 years that demonstrate the positive effect of bambermycins on expressed antimicrobial resistance. Investigators observed that supplementation of swine diets with flavomycin, either alone or in combination with chlortetracycline, significantly decreased the number of *E coli* that contained R-factor plasmids coding for tetracycline resistance.[26] The same investigators also observed that flavomycin has a similar mitigating effect on *E coli* resistance to the antimicrobial streptomycin.[27] The ability of flavomycin to reduce the level of expressed antimicrobial resistance by modulating R-factor plasmids has since been described as a "plasmid-curing effect."[28] Flavomycin carries a label for swine; however, it has been used more extensively in poultry feeding programs. A promising item of consideration relative to the use of bambermycins in livestock production is the fact that an equivalent preparation from this class does not exist for human use. Therefore, use of flavomycin in food-producing animals should not contribute to concerns related to antimicrobial resistance in humans.

Implications

- Under the conditions of this study, oregano oil and multi-component carbohydrases, fed individually or in combination, are inferior to flavomycin as growth-promoting supplements for nursery pigs.
- More research is warranted to assess the potential value of multi-component carbohydrases in swine diets.
- Flavomycin may represent a viable antimicrobial growth promotant for nursery-age pigs because of its capacity to improve pig performance and lack of an analogous preparation in use in human medicine.

Acknowledgments

The authors are grateful to Van Beek Scientific for their assistance and to the Lew Runnels Endowment for financial support of this research endeavor. The staff of the Purdue University Animal Sciences Research and Education Center is acknowledged for their efforts on this project.

References

1. Cromwell GL. Antimicrobial and promicrobial agents. In: Lewis AJ, Southern LL, eds. *Swine Nutrition.* 2nd ed. New York: CRC Press. 2001:401–426.

*2. Gorbach SL. Antimicrobial use in animal feed – time to stop [editorial]. *New Engl J Med.* 2001;345:1202–1203.

3. Langlois BE, Dawson KA, Leak I, Aaron DK. Antimicrobial resistance of fecal coliforms from pigs in a herd not exposed to antimicrobial agents for 126 months. *Vet Microbiol.* 1988;18:147–153.

4. Aarestrup FM, Seyfarth AM, Emborg H-D, Pederson K, Hendriksen RS, Bager F. Effect of abolishment of the use of antimicrobial agents for growth promotion on occurrence of antimicrobial resistance in fecal enterococci from food animals in Denmark. *Antimicrob Agents Chemother.* 2001;45:2054–2059.

5. Casewell M, Friis C, Marco E, McMullin P, Phillips I. The European ban on growth-promoting antibiotics and emerging consequences for human and animal health. *J Antimicrob Chemother.* 2003;52:159–161.

6. Thomke S, Elwinger K. Growth promotants in feeding pigs and poultry. III. Alternatives to antibiotic growth promotants. *Ann Zootech.* 1998;47:245–271.

7. Lambert RJW, Skandamis PN, Coote PJ, Nychas GJE. A study of the minimum inhibitory concentration and mode of action of oregano essential oil, thymol and carvacrol. *J Appl Microbiol.* 2001;91:453–462.

*8. van Krimpen MM, Binnendijk GP. Ropadiar as alternative for antimicrobial growth promoter in diets of weanling pigs [in Dutch]. *Rapport Praktijkonderzoek Veehouderij.* 2001;205:14.

9. Bilkei G, Gertenbach W. Retrospective evaluation of the combined effect of high vitamin E and oregano phytogenic feed additives on the performance of "slow growing" fattening pigs. *Biologische Tiermedizin.* 2001;18:83–87.

10. Kies A, Holkenborg ABMK, Schulze HK. Enzyme research and application in balance. *Feed Mix.* 2002;10:18–21.

11. Waldroup P. Phytase: vital in phosphorus management. *Feed Mix.* 2004;12:30–31.

12. Omogbenigun FO, Nyachoti CM, Slominski BA. Dietary supplementation with multienzyme preparations improves nutrient utilization and growth performance in weaned pigs. *J Anim Sci.* 2004;82:1053–1061.

13. Kim SW, Knabe DA, Hong KJ, Easter RA. Use of carbohydrases in corn-soybean meal-based nursery diets. *J Anim Sci.* 2003;81:2496–2504.

14. National Research Council. *Nutrient Requirements of Swine.* 10th rev ed. Washington, DC: National Academy Press. 1998.

*15. A bill to amend the Federal Food, Drug, and Cosmetic Act to preserve the effectiveness of medically important antibiotics used in the treatment of human and animal diseases, S 1460, 108th Cong, 1st Sess (2003).

*16. Tsinas AC, Giannakopoulos CG, Papasteriades A, Alexopoulos C, Mavromatis J, Kyriakis SC. Use of origanum essential oils as growth promoter in pigs. In: *Proc 15th Intl Pig Vet Soc Congress.* Birmingham, England. 1998;15:221.

17. Mauch C, Bilkei G. Strategic application of oregano feed supplements reduces sow mortality and improves reproductive performance – a case study. *J Vet Pharmacol Therap.* 2004;27:61–63.

18. Allan P, Bilkei G. Oregano improves reproductive performance of sows. *Theriologenology.* 2005;63:716–721.

19. Amrik B, Bilkei G. Influence of farm application of oregano on performances of sows. *Can Vet J.* 2004;45:674–677.

20. Neill CR, Nelssen JL, Tokach MD, Goodband RD, DeRouchey JM, Dritz SS, Groesbeck CN, Brown KR. Effects of oregano oil on growth performance of nursery pigs. *J Swine Health Prod.* 2006;14:312–316.

21. Ragland D, Schneider J, Stevenson D, Hill MA. Oregano oil as an alternative to antimicrobials in nursery diets. *J Swine Health Prod.* 2007;15:346–351.

22. Bedford MR. Mode of action of feed enzymes. *J Appl Poult Res.* 1993;2:85–92.

23. Chesson A. Feed enzymes. *Anim Feed Sci Technol.* 1993;45:65–79.

24. Pettey LA, Carter SD, Senne BW, Shriver JA. Effects of ß-mannanase addition to corn-soybean meal diets on growth performance, carcass traits, and nutrient digestibility of weanling and growing-finishing pigs. *J Anim Sci.* 2002;80:1012–1019.

25. Pan B, Li D, Piao X, Zhang L, Guo L. Effect of dietary supplementation with α-galactosidase preparation and stachyose on growth performance, nutrient digestibility and intestinal bacterial populations of piglets. *Arch Anim Nutr.* 2002;56:327–337.

*26. Sokol A, Kromery V, Federic F, Rajtar V, Janouskova J. The influence of flavomycin on the elimination of R-factors of *Escherichia coli* in vitro. *Folia Microbiol.* 1973;18:176.

*27. Federic F, Sokol A, Rajtar V, Simansky S, Hamrova Z, Sovik M, Polakova O. The dynamic of changes in resistance to antibiotics in pigs fed flavomycin. *Folia Microbiol.* 1973;18:176–177.

28. van den Bogaard AE, Hazen M, Hoyer M, Oostenbach P, Stobberingh EE. Effects of flavophospholipol on resistance in fecal *Escherichia coli* and enterococci of fattening pigs. *J Antimicrob Chemother.* 2002;46:110–118.

* Non-refereed references.

Conversion tables

Weights and measures conversions

Common (US)	Metric	To convert	Multiply by
1 oz	28.35 g	oz to g	28
1 lb (16 oz)	453.59 g	lb to kg	0.45
2.2 lb	1 kg	kg to lb	2.2
1 in	2.54 cm	in to cm	2.54
0.39 in	1 cm	cm to in	0.39
1 ft (12 in)	0.31 m	ft to m	0.3
3.28 ft	1 m	m to ft	3.28
1 mi	1.6 km	mi to km	1.6
0.62 mi	1 km	km to mi	0.6
1 sq in	6.5 cm^2	sq in to cm^2	6.5
0.15 sq in	1 cm^2	cm^2 to sq in	0.15
1 sq ft	0.09 m^2	sq ft to m^2	0.09
11.11 sq ft	1 m^2	m^2 to sq ft	11
1 cu ft	0.03 m^3	cu ft to m^3	0.03
35.32 cu ft	1 m^3	m^3 to cu ft	35
1 c (cup)	0.24 L	c to L	0.24
4.1667 c	1 L	L to c	4.2
1 gal (128 fl oz)	3.8 L	gal to L	3.8
0.264 gal	1 L	L to gal	0.26
1 qt (32 fl oz)	946.36 mL	qt to L	0.95
33.8138 oz	1 L	L to qt	1.1

Temperature equivalents

$°F = (°C \times 9/5) + 32$

$°C = (°F - 32) \times 5/9$

°C	°F
0	32
10	50
15.5	60
16	61
18.3	65
21.1	70
23.8	75
26.6	80
28	82
29.4	85
32.2	90
38.8	102
39.4	103
40.0	104
40.5	105
41.1	106
100	212

Conversion chart, kg to lb

Pig size	Kg	Lb
Birth	1.5 – 2.0	3.3 – 4.4
Weaning	3.5	7.7
	5	11
	10	22
Nursery	15	33
	20	44
	25	55
	30	66
Grower	45	99
	50	110
	60	132
Finisher	90	198
	100	220
	105	231
	110	242
	115	253
Sow	135	300
	300	661
Boar	360	800

1 tonne = 1000 kg

1 ppm = 0.0001% = 1 mg/kg = 1 g/tonne

1 ppm = 1 mg/L