The effect of polyphenols on the performance and antioxidant status of sows and piglets

Krzysztof Lipiński, Zofia Antoszkiewicz, Magdalena Mazur-Kuśnirek, Daniel Korniewicz and Sylwia Kotlarczyk

aKatedra Żywienia Zwierząt i Paszoznawstwa, University of Warmia and Mazury in, Olsztyn, Poland; bCargill Polska Sp. z.o.o, Poland Rolna, Kiszkowo, Poland

ABSTRACT
The aim of this study was to determine the efficacy of polyphenols in pigs. The experiment was performed on 52 sows divided into 4 groups. Untreated control sows (group 1) were not administered vitamin E in the premixes. The diets of the experimental animals were supplemented with vitamin E in the amount of 50 mg (group 2) or 100 mg/kg diets (group 3) (gestation diets) and 75 mg (group 2) or 150 mg/kg diets (group 3) (lactation diets). The diets of group four sows were supplemented with vitamin E (50/75 mg/kg, gestation/lactation) and Proviox (polyphenols) (50/75 mg/kg, gestation/lactation). The influence of different dietary inclusion levels of vitamin E and vitamin E/polyphenols on the performance, vitamin E concentrations, and antioxidant status of sows and piglets was analysed. The sows whose diets were supplemented with vitamin E and polyphenols (50:50) were characterised by similar fertility, mating success, and litter performance as the group whose diets were supplemented with vitamin E only. The results of this study indicate that sows receiving vitamin E and polyphenols and their progeny were characterised by similar or improved vitamin E status and improved antioxidant status compared with the animals whose diets were supplemented with 100 mg/150 mg of vitamin E/kg diet. It can be concluded that the replacement of 50% of dietary vitamin E with polyphenols did not compromise the growth performance of sows or piglets and improved their antioxidant status.

ARTICLE HISTORY
Received 3 April 2018
Revised 11 July 2018
Accepted 18 July 2018

KEYWORDS
Polyphenols; vitamin E; antioxidant status; pigs

Introduction
Genetic progress has contributed to improving the reproductive potential of sows and the profitability of livestock production in commercial farms. As a result, litter birth weight and the number of piglets weaned per sow per year have increased significantly in recent years (Foxcroft 2012; Szymańska 2012). Despite the above, gestation, the perinatal period, weaning (Fan et al. 2015), and high stocking density in commercial farms where pigs are kept on slatted floors are sources of considerable stress for animals. These factors lead to a rapid increase in the concentrations of reactive oxygen species (ROS) and induce oxidative stress (Frankic and Salobir 2011; Lipko-Przybylska and Kankofer 2012; Durand et al. 2013). The resulting redox imbalance can induce irreversible structural and functional changes in cells, including DNA damage, amino acid modification, protein fragmentation, lipid peroxidation in cell membranes, apoptosis and cell necrosis (Lykkesfeldt and Svendsen 2007; Lipiński et al. 2017). These changes influence the animals’ health status and performance, and the quality of animal products (Durand et al. 2013; Gobert et al. 2013; Ott et al. 2014). Animal nutrition programmes have to be continuously improved, with special emphasis on feed additives. The supplementation of animal diets with vitamin E improves the health status and the reproductive performance of sows. Vitamin E is the main antioxidant that counteracts lipid peroxidation in cells. Alpha-tocopherol is localised in cell membranes and plasma lipoproteins, and it protects phospholipids and polyunsaturated fatty acids against oxidation (Sosnowska et al. 2011; Amazan et al. 2014; Karpinska and Gromadzka 2013). Tocopherols are derived from vegetable oils, but synthetic forms of vitamin E are also available (Bramley et al. 2000, Lynch et al. 2001). In recent years, food producers and consumers have shown an increasing interest in the origin of feed...
additives, and particular attention has been paid to natural compounds. Polyphenols are potent antioxidants whose effectiveness is comparable to that of vitamin E (Lipiński et al. 2017). Polyphenols constitute one of the largest groups of bioactive compounds derived from plants. They are present in fruit, vegetables, herbs, spices, red wine, black and green tea. Polyphenols also demonstrate anti-inflammatory, antiviral and anti-carcinogenic properties (Zhong and Zhou 2013; Sural 2014; Brenes et al. 2016). The results of numerous in vitro and in vivo studies revealed a beneficial influence of these bioactive compounds in animal nutrition due to their antioxidant, bactericidal and immunostimulatory activities (Alonso et al. 2002, Torres et al. 2002, Viveros et al. 2011; Fiesel et al. 2014; Verhelst et al. 2014; Gerasopoulos et al. 2015). The mechanisms underlying the biological effects of polyphenols are currently being investigated.

The following research hypothesis was tested: due to their antioxidant properties, polyphenols can partially replace vitamin E in diets fed to sows in the perinatal period. The aim of this study was to determine the effect of dietary supplementation with synthetic vitamin E and plant polyphenols on the performance and antioxidant status of sows and piglets.

Materials and methods

Animals, experimental design, and diets

The experiment was approved by the Local Ethics Committee for Animal Experimentation in Olsztyn, Poland. It was performed on 52 sows (primiparous and multiparous) of the PIC genetic line. The animals were reared in a continuous farrowing system, and they were divided into four groups of 13 pigs each. Untreated control group sows (group 1) did not receive vitamin E in the premixes. The diets of the experimental sows were supplemented with vitamin E (α-tocopheryl acetate) in the amount of 50 (group 2) or 100 (group 3) mg/kg diets (gestation diets) and 75 (group 2) or 150 (group 3) mg/kg diets (lactation diets). The diets of group 4 sows were supplemented with vitamin E (50/75 mg/kg, gestation diets/lactation diets) and Proviox polyphenols (50/75 mg/kg, gestation diets/lactation diets) (Table 1).

Sows were fed mashed diets, including gestation diets administered in the first 90 days of pregnancy and lactation diets administered between 90 days of pregnancy until the end of lactation (Table 1). The diets differed in the content of vitamin E (50% D,L-α-tocopheryl acetate) and the Proviox (Provimi, France) preparation containing calcium carbonate and plant polyphenols (anthocyanidin, flavonol, catechin, procyanidin) (Table 2).

The analysed performance traits were the average reproductive cycle, fertilisation rate, culling rate and reasons for culling, and the weaning-to-oestrus interval. The analysed litter performance traits were the number and birth weight of piglets born alive and the number of piglets weaned at 21 days of age.

Sample collection and laboratory analyses

Feed samples were assayed for the content of dry matter (DM), crude ash, crude protein (CP), ether extract (EE), and crude fibre (CF) by standard methods.
Vitamin E concentrations were measured by chromatography (HPLC) (Shimadzu, Japan) in accordance with Polish Standard PN-EN ISO 6867: 2002.

Blood samples were collected from sows on three dates: during mating, during the perinatal period (around 1 day after parturition), and on lactation day 28. Blood samples were collected from piglets on lactation day 21. The activity of superoxide dismutase (SOD) and glutathione peroxidase (GSH-Px) was determined in heparinised whole blood. Total antioxidant status (TAS) and the concentrations of vitamins A and E were determined in the blood serum. Blood samples were stored at a temperature of $-20^\circ C$ until analysis.

Total antioxidant status, SOD, and GSH-Px activity were determined with the use of the Sigma-Aldrich kit according to the manufacturer’s recommendations. The activity of SOD was measured as the percent inhibition of the rate of formazan dye formation (505 nm wavelength). The activity of GSH-Px in heparinised whole blood was determined with the use of cumene hydroperoxide. In the presence of glutathione reductase and NADPH, oxidised glutathione is converted to a reduced form, and NADPH is oxidised to NADP$^+$ (340 nm wavelength). Total antioxidant status was determined in the blood serum based on the colour reaction with the ABTS stock solution [(2,2-azino-bis(3-ethylbenzthiazoline- 6-sulfonic acid)] and metmyoglobin. The antioxidants present in the analysed samples reduce the intensity of bluish-green colour proportionally to their concentrations (600 nm wavelength). The analysis was performed in the spectrophotometer (EPOLL-30 ECO, Poll Ltd., Warsaw, Poland).

Serum samples (1 mL) were deproteinised with anhydrous ethanol (1 mL), extracted with 5 mL of n-hexane (Vortex 5') and centrifuged (3000 g, 10', temp. $4^\circ C$). The resulting supernatant in the amount of 4 mL was evaporated to dryness under nitrogen, diluted in 1 mL of 96% ethanol. Tocopherol and retinol concentrations were measured by chromatography (HPLC) (Shimadzu, Japan), according to the method described by Rettenmaier and Schüep (1992).

**Statistical analysis**

The results were processed statistically by one-way analysis of variance and Duncan’s test. The experimental unit was an individual animal. The arithmetic mean ($x$), standard error of the mean (SEM), and the level of significance ($p < .05$; $p < .01$) were given for all results. All calculations were performed in the Statistica 10 Program.

**Results**

There were no significant differences in the performance of sows (Table 3). Dietary supplementation with the polyphenol preparation (Proviox) did not exert a significant effect on the number of culled sows, but contributed to a shorter weaning-to-remating interval ($p = .09$).

The number of weaned piglets per litter tended to be higher ($p = .06$) when sow diets were supplemented with vitamin E and polyphenols (11.73, 11.82, 11.55 vs. 9.80) (Table 4). Litter weight was significantly ($p < .05$) higher in the experimental groups (18.50, 19.07, 19.34 kg) than in the control group (15.59 kg). Litter weight at weaning was significantly ($p < .05$) higher (85.05, 84.33, 85.98 kg) in groups where sow diets were supplemented with vitamin E and Proviox than in the control group (67.85 kg). Sows receiving diets supplemented with polyphenols and vitamin E were characterised by similar fertility, mating success and litter performance as sows whose diets were supplemented with vitamin E.

In group 4 (50/75 mg of vitamin E/kg diet + polyphenols), serum $\alpha$-tocopherol concentrations at farrowing and at weaning were similar to those noted

| Table 3. Sow performance. |
|---------------------------|

| Groups                     | Control | 50/75 vit E | 100/150 vit E | 50/75 vit E + 50/75 polyphenols | SEM | p    |
|----------------------------|---------|-------------|---------------|-------------------------------|-----|------|
| Sows, n                    | 13      | 13          | 13            | 13                            |     |      |
| Primiparous                | 1       | 1           | 1             | 1                             |     |      |
| Multiparous                | 12      | 12          | 12            | 12                            |     |      |
| Average sow parity         | 3.23    | 3.85        | 3.46          | 3.50                          | 0.183| .690 |
| Non-pregnant sows after first mating, n  | 5      | 3           | 2             | 2                             |     |      |
| Non-pregnant sows after second mating, n  | 3      | 2           | 2             | 2                             |     |      |
| Farrowing rate, %          | 76.92   | 84.62       | 84.62         | 84.62                         | 5.143| .999 |
| Culled sows, n             | 3       | 2           | 2             | 2                             |     |      |
| Reproductive failure       | 3       | 2           | 2             | 2                             |     |      |
| Subsequent performance     |         |             |               |                               |     |      |
| Weaning-to-oestrus interval, d | 5.40   | 5.09        | 5.64          | 5.00                          | 0.102| .093 |
| Weaning-to-remating interval, d | 14.86  | 9.89        | 7.70          | 5.10                          | 1.373| .100 |
| Farrowing rate, %          | 70.00   | 80.00       | 90.91         | 90.91                         | 5.820| .544 |
in group 3 (100/150 mg of vitamin E/kg diet), and higher \( (p < .001) \) compared with sows from other groups (Table 5). In sows receiving supplemental vitamin E, a linear \( (p < .001) \) increase in serum vitamin A concentrations was observed at farrowing. Group 3 (100/150 mg of vitamin E/kg) and group 4 (vitamin E + Proviox) sows were characterised by higher serum vitamin A concentrations than group 2 pigs (50/75 mg of vitamin E/kg diet). Dietary supplementation with vitamin E and polyphenols increased \( (p < .05) \) serum vitamin A levels in sows. Vitamin E supplementation had no effect on serum vitamin A concentrations at weaning.

A higher increase in serum TAS was noted in sows receiving vitamin E and polyphenols than in sows administered only vitamin E \( (p < .001) \) (Table 6). The
The highest SOD activity was observed in sows administered vitamin E and Proviox, especially at weaning \((p < .001)\). The activity of GSH-Px in the blood was significantly lower \((p /C20 < .001)\) in control group sows than in sows receiving vitamin E. The highest GSH-Px activity was observed in sows administered vitamin E and polyphenols during both farrowing and weaning \((p /C20 < .001)\).

The supplementation of sow diets with vitamin E increased \((p /C20 < .001)\) serum \(\alpha\)-tocopherol levels (Table 7). When lactating sows received 150 mg of vitamin E/kg diet, their progeny had higher \((p < .001)\) serum \(\alpha\)-tocopherol concentrations than the offspring of other sows. The highest serum concentration of vitamin A was observed in piglets whose mothers received vitamin E and polyphenols \((p \leq .001)\).

The supplementation of sow diets with vitamin E increased \((p \leq .001)\) serum \(\alpha\)-tocopherol levels (Table 7). When lactating sows received 150 mg of vitamin E/kg diet, their progeny had higher \((p < .001)\) serum \(\alpha\)-tocopherol concentrations than the offspring of other sows. The highest serum concentration of vitamin A was observed in piglets whose mothers received vitamin E and polyphenols \((p \leq .001)\).

The supplementation of sow diets with vitamin E increased \((p \leq .001)\) serum \(\alpha\)-tocopherol levels (Table 7). When lactating sows received 150 mg of vitamin E/kg diet, their progeny had higher \((p < .001)\) serum \(\alpha\)-tocopherol concentrations than the offspring of other sows. The highest serum concentration of vitamin A was observed in piglets whose mothers received vitamin E and polyphenols \((p \leq .001)\).

Serum TAS concentrations were higher in the groups fed vitamin E and polyphenols-supplemented diets than in non-supplemented groups \((p \leq .001)\). Serum SOD and GSH-Px activity was highest in the offspring of sows whose diets were supplemented with vitamin E and polyphenols than in piglets whose mothers received only vitamin E.

Discussion

Mating success, embryo implantation, duration of pregnancy, and lactation considerably influence litter size. Pregnancy and lactation pose a considerable metabolic challenge for sows. The demand for energy increases with oxygen uptake, which contributes to the production of ROS (Agarwal et al. 2003; Tan et al. 2015). During that time, sows are particularly susceptible to oxidative damage resulting from a deficiency of \(\alpha\)-tocopherol and retinol (Berchieri-Ronchi et al. 2011; Fan et al. 2015). The above intensifies lipid peroxidation and contributes to the synthesis of mutagenic and carcinogenic malondialdehyde (MDA) in the major organs (Lykkesfeldt and Svendsen 2007). In consequence, milk production, reproductive performance, and longevity are significantly compromised in sows (Berchieri-Ronchi et al. 2011).

Enzymatic and non-enzymatic antioxidants participate in the maintenance of the redox potential. They inhibit free radical reactions and remove the produced ROS (Birben et al. 2012). Antioxidants are classified as high-molecular-weight (antioxidant triad) and low-molecular-weight (retinol, tocopherols, glutathione, polyphenols) antioxidants (Lykkesfeldt and Svendsen 2007; Durand et al. 2013; Landete 2013). Superoxide dismutase removes superoxide anion radicals by converting them to hydrogen peroxide which is decomposed into water in the presence of catalase and GSH-Px. These enzymes are highly effective in inhibiting oxidation processes (Lykkesfeldt and Svendsen 2007). Polyphenols protect cells against oxidative damage, minimise adverse health consequences and oxidative stress (D’Archivio et al. 2007). The antioxidant properties of polyphenols can be attributed to their unique chemical structure and the presence of hydroxyl groups which participate in the reduction of free radicals. Phenolic groups can accept unpaired electrons and create stable phenoxyl radicals (Landete 2013; Zhong and Zhou 2013; Brenes et al. 2016).

Polyphenols indirectly stimulate the activity of antioxidant enzymes and contribute to increasing the concentrations of low-molecular-weight antioxidants such as \(\alpha\)-tocopherol (Rice-Evans et al. 1996; Pietta 2000; Masella et al. 2005). Increased levels of vitamin E provide effective protection against ROS and minimise oxidative stress in pigs (Landete 2013).

In the present study, SOD and GSH-Px were more active in the blood serum of pigs administered polyphenols and vitamin E during farrowing and weaning, which indicates that these compounds exert synergistic effects. The partial replacement of vitamin E with polyphenols improved the antioxidant status of sows and piglets without compromising fertility, mating success and litter performance.

Fan et al. (2015) evaluated the influence of catechins on the reproductive performance and

### Table 7. Concentrations of vitamins E and A (mg/mL of serum), total antioxidant status (TAS mmol/L of serum), and the activity of superoxide dismutase (SOD U/mL of serum) and glutathione peroxidase (GSH-Px U/mL of blood) in the serum and blood of piglets at 21 days of age.

| Specification | Control | 50/75 vit E | 100/150 vit E | 50/75 vit E + 50/75 polyphenols | SEM | \(p\) |
|---------------|---------|-------------|---------------|-------------------------------|-----|-----|
| \(\alpha\)-Tocopherol | 0.52^a | 1.41^c | 1.61^b | 1.48^b | 0.070 | <.001 |
| Retinol | 0.078^d | 0.16^e | 0.20^d | 0.25^c | 0.011 | <.001 |
| TAS | 0.86^c | 1.16^e | 1.18^c | 1.24^c | 0.026 | <.001 |
| SOD | 98.01^a | 100.61^b | 129.54^ab | 134.80^a | 2.743 | <.001 |
| GSH-Px | 27.40^c | 29.12^d | 29.91^c | 34.58^a | 0.457 | <.001 |

\(^{a,b,p} p < .05\)

\(^{A,B,C,D,p} p \leq .01\)
antioxidant status of sows during early pregnancy. They observed an increase in SOD and CAT activity, a decrease in serum MDA levels, a higher number of piglets born alive and a lower number of stillborn piglets in sows whose diets were supplemented with polyphenols relative to control group pigs. In a study by Maghin et al. (2016), dietary supplementation with algae-derived polyphenols did not affect the antioxidant status of pigs, but increased the number of piglets born alive in the group of sows receiving the above feed additive relative to the control group.

Flis et al. (2010) found that diets rich in α-linolenic acid (ALA) with a higher content of polyphenols derived from barley and triticale increased the activity of SOD and GSH-Px and serum TAS values in pigs. In another experiment, growing-finishing pigs whose diets were supplemented with vitamin E were characterised by higher SOD activity and tocopherol levels than in the remaining groups (Sobotka et al. 2012).

Contrary results were reported by Augustin et al. (2008) and Gessner et al. (2013) who did not observe an improvement in the antioxidant status of pigs whose diets were supplemented with polyphenols extracted from green tea, grape seeds and grape pomace.

Birth and the first breath of atmospheric oxygen which intensifies ROS production are the first critical events in young animals’ lives (Gaál et al. 2006; Solberg et al. 2007). Weaning is the second critical event in piglets, and the replacement of liquid milk with dry feed causes various disorders (Campbell et al. 2013). Enzymatic digestion is not fully developed in young piglets (Leonard et al. 2011), which can decrease nutrient digestibility and reduce body weight gains (Wijtten et al. 2011; Hu et al. 2013). In the first hours postpartum, the colostrum is characterised by elevated levels of immunoglobulins, antioxidants and antioxidant enzymes (Kielland et al. 2015; Chen et al. 2016). Sows should be fed balanced diets supplemented with antioxidants. Alpha-tocopherol is not fully transferred across the porcine placenta (Pinelli-Saavedra and Scaife 2005). Vitamin E concentrations in the porcine blood plasma, tissues, colostrum and milk are highly correlated with the administered dose of dietary vitamin E (Pinelli-Saavedra 2003). In consequence, vitamin E levels in piglets are determined by the amount of vitamin E ingested with the mother’s milk (Pinelli-Saavedra et al. 2008).

In the current study, reduced oxidative stress during farrowing and weaning contributed to higher litter weight and increased the body weights of piglets at weaning. The offspring of sows whose diets were supplemented with both vitamin E and polyphenols were characterised by improved antioxidant status, higher GSH-Px and SOD activity and higher serum retinol levels, compared with the piglets from the remaining groups.

Dietary supplementation with polyphenols from olive mill wastewater improved the antioxidant status of blood and tissues (TAC, GSH-Px, and CAT) and decreased the thiobarbituric acid-reactive substances values, an indicator of lipid peroxidation, in weaned piglets compared with control group (Gerasopoulos et al. 2015). Similar results were reported by other authors who observed an improvement in the antioxidant status, an increase in the activity of antioxidant enzymes and a decrease in plasma MDA levels in weaned piglets fed diets supplemented with polyphenols. Dietary polyphenol supplementation improved the health status and growth performance of piglets (Zhang et al. 2014; Hao et al. 2015; Chen et al. 2018).

Conclusions

The sows whose diets were supplemented with vitamin E and polyphenols (50:50) were characterised by similar fertility, mating success and litter performance as the animals whose diets were supplemented with vitamin E only. The results of this study indicate that sows receiving vitamin E and Proviox and their progeny were characterised by similar or improved vitamin E status and improved antioxidant status compared with the animals whose diets were supplemented with 100 mg/150 mg of vitamin E/kg diet. It can be concluded that the replacement of 50% of dietary vitamin E with polyphenols did not compromise the growth performance of sows or piglets and improved their antioxidant status.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Krzysztof Lipiński  http://orcid.org/0000-0001-8662-0531
Magdalena Mazur-Kuśnirek  http://orcid.org/0000-0003-0913-012X

References

Agarwal A, Saleh RA, Bedaiwy MA. 2003. Role of reactive oxygen species in the pathophysiology of human reproduction. Fertil Steril. 79:829–843.
Alonso AM, Guillé DA, Barroso CG, Puertas B, García A. 2002. Determination of antioxidant activity of wine byproducts and its correlation with polyphenolic content. J Agric Food Chem. 50:5832–5836.

Amazan D, Cordero G, López-Bote CJ, Lauridsen C, Rey Al. 2014. Effects of oral micellized natural vitamin E (D-α-tocopherol) v. synthetic vitamin E (DL-α-tocopherol) in feed on α-tocopherol levels, stereoisomer distribution, oxidative stress and the immune response in piglets. Animal 8:410–419.

AOAC International. 2005. Official methods of analysis of AOAC International. Rockville (MD): AOAC International.

Augustin K, Blank R, Boesch-Saadamandi C, Frank J, Wolframb S, Rimbach G. 2008. Dietary green tea polyphenols do not affect vitamin E status, antioxidant capacity and meat quality of growing pigs. J Anim Physiol Anim Nutr (Berl). 92:705–711.

Berchieri-Ronchi CB, Kim SW, Zhao Y, Correa CR, Yeum KJ, Ferreira ALA. 2011. Oxidative stress status of highly prolific sows during gestation and lactation. Animal 5:1774–1779.

Birben E, Sahiner UM, Sackesen C, Erzurum S, Kalayci O. 2012. Oxidative stress and antioxidant defense. World Allergy Org. 5:9.

Bramley PM, Elmadfa I, Kafatos A, Kelly FJ, Manios Y, Roxborough HE, Schuch W, Sheehy PJA, Wagner K-H. 2000. Review vitamin e. J Sci Food Agric. 80:913–938.

Brener A, Viveros A, Chamorro S, Arija I. 2016. Use of polyphenol-rich grape by-products in monogastric nutrition. A review. Anim Feed Sci. 211:1–17.

Campbell JM, Crenshaw JD, Polo J. 2013. The biological stress of early weaned piglets. J Anim Sci Biotechnol. 4:19.

Chen J, Li Y, Yu B, Chen D, Mao X, Zheng P, Luo J, He J. 2018. Dietary chlorogenic acid improves growth performance of weaned pigs through maintaining antioxidant capacity and intestinal digestion and absorption function. J Anim Sci. 96:1108–1118.

Chen J, Han JH, Guan WT, Chen F, Wang CX, Zhang YZ, Lv YT, Lin G. 2016. Selenium and vitamin E in sow diets: I. Effect on antioxidant status and reproductive performance in multiparous sows. Anim Feed Sci Technol. 221:101–123.

D’Archivio M, Filesi C, Di Benedetto R, Gargiulo R, Giovannini C, Masella R. 2007. Polyphenols, dietary sources and bioavailability. Ann. Ist. Super Sanita 43:348–361.

D’Archivio M, Filesi C, Di Benedetto R, Gargiulo R, Giovannini C, Masella R. 2007. Polyphenols, dietary sources and bioavailability. Ann. Ist. Super Sanita 43:348–361.

Durand D, Damon M, Gobert M. 2013. Oxidative stress in farm animals: general aspects. Cah Nutr Diet 48:225–232.

Fan Z, Xiao Y, Chen Y, Wu X, Zhang G, Wang Q, Xie C. 2015. Effects of catechins on litter size, reproductive performance and antioxidative status in gestating sows. Anim Nutr. 1:271–275.

Fiesel A, Gessner DK, Erika Most E, Eder K. 2014. Effects of dietary polyphenol-rich plant products from grape or hop on pro-inflammatory gene expression in the intestine, nutrient digestibility and faecal microbiota of weaned pigs. BMC Vet Res. 10:196–206.

Flis M, Sobotka W, Antoszkiewicz Z, Lipiński K, Zduńczyk Z. 2010. The effect of grain polyphenols and the addition of vitamin E to diets enriched with ω-linolenic acid on the antioxidant status of pigs. J Anim Feed Sci. 19:539–553.

Foxcroft GR. 2012. Reproduction in farm animals in an era of rapid genetic change: will genetic change outpace our knowledge of physiology? Reprod Dom Anim. 47:313–319.

Frankie T, Salobir J. 2011. In vivo antioxidant potential of Sweet chestnut (Castanea sativa Mill.) wood extract in young growing pigs exposed to n-3 PUFA-induced oxidative stress. J Sci Food Agric. 91:1432–1439.

Gaal T, Ribiczeiñ-Szabó P, Stadler K, Jakus J, Reiczigel J, Kövér P, Mezes M, Sümeghy L. 2006. Free radicals, lipid peroxidation and the antioxidant system in the blood of cows and newborn calves around calving. Comp Biochem Physiol Part B 143:391–396.

Gerasopoulos K, Stagos D, Petrotos K, Kokkas S, Kantas D, Goulas P, Kouretas D. 2015. Feed supplemented with polyphenolic by product from olive mill wastewater processing improves the redox status in blood and tissues of piglets. Food Chem Toxicol. 86:319–327.

Gessner DK, Fiesel A, Most E, Dinges J, Wen G, Ringsies R, Eder K. 2013. Supplementation of a grape seed and grape marc meal extract decreases activities of the oxidative stress-responsive transcription factors NF-κB and Nrf2 in the duodenal mucosa of pigs. Acta Vet Scand. 55:18–28.

Gobert M, Damon M, Durand D. 2013. Oxidative stress and nutritional quality of animal products. Cah Nutr Diet 48:225–232.

Hao R, Li Q, Zhao J, Li H, Wang W, Gao J. 2015. Effects of grape seed procyanidins on growth performance, immune function and antioxidant capacity in weaned piglets. LivestSci. 178:237–242.

Hu C, Xiao K, Luan Z, Song J. 2013. Early weaning increases intestinal permeability, alters expression of cytokine and tight junction proteins, and activates mitogen-activated protein kinases in pigs. J Anim Sci. 91:1094–1101.

Karpinska A, Gromadzka G. 2013. Stres oksydacyjny i naturalne mechanizmy antyoksydacyjne- znaczenie w procesie neurodegeneracji. Od mechanizmów molekularnych do strategii terapeutycznych. Postepy Hig Med Dośw. 67:43–53.

Kießling C, Rootwelt V, Reksen O, Framstad T. 2015. The association between immunoglobulin G in sow colostrum and piglet plasma. J Anim Sci. 93:4453–4462.

Landete JM. 2013. Dietary intake of natural antioxidants: vitamins and polyphenols. Crit Rev Food Sci Nutr. 53:706–721.

Leonard SG, Sweeney T, Bahar B, Lynch BP, O’Doherty JV. 2011. Effects of dietary seaweed extract supplementation in sows and post-weaned pigs on performance, intestinal morphology, microbial microflora and immune status. Brit J Nutr. 106:688–699.

Lipiński K, Mazur M, Antoszkiewicz Z, Purwin C. 2017. Polyphenols in monogastric nutrition–a review. Ann Anim Sci. 17:41–58.

Lipko-Przybylska J, Kanferko M. 2012. Antioxidant defence of colostrum and milk in consecutive lactations in sows. Ir Vet J. 65:4–8.

Lykkefjeldt J, Svendsen O. 2007. Oxidants and antioxidants in disease: oxidative stress in farm animals. Vet J. 173:502–511.

Lynch A, Kerry JP, Buckley DJ, Morrissey PA, Lopez-Bote C. 2011. Use of high pressure liquid chromatography (HPLC) for the determination of cda-tocopherol levels in forage and its correlation with polyphenolic content. J Agric Food Chem. 59:524.

Maghin F, Rossi R, Ratti S, Chiapparini S, Corino C. 2016. Dietary supplementation with algae and polyphenols in...
lactating sows: effects on sows and piglets’ performance. Int J Health Anim Sci Food Safe 3:1.
Masella R, Di Benedetto R, Vari R, Filesi C, Giovannini C. 2005. Novel mechanisms of natural antioxidant compounds in biological systems: involvement of glutathione and glutathione-related enzymes. J Nutr Biochem. 16:577–586.
Ott S, Soler L, Moons CPH, Kashiha MA, Bahr C, Vandermeulen J, Janssens S, Gutiérrez AM, Escrivano D, Cerón JJ, et al. 2014. Different stressors elicit different responses in the salivary biomarkers cortisol, haptoglobin, and chromogranin A in pigs. Res Vet Sci. 97:124–128.
Pietta PG. 2000. Flavonoids as antioxidants. J Nat Prod. 63:1035–1042.
Pinelli-Saavedra A. 2003. Vitamin E in immunity and reproductive performance in pigs. Reprod Nutr Dev. 43:397–408.
Pinelli-Saavedra A, Scaife JR. 2005. Pre- and postnatal transfer of vitamin E and C to piglets in sows supplemented with vitamin E and vitamin C. Livest Prod Sci. 97:231–240.
Pinelli-Saavedra A, Calderon De La Barca AM, Hernandez J, Valenzuela R, Scaife JR. 2008. Effect of supplementing sow’s feed with alpha-tocopherol acetate and vitamin C on transfer of alpha-tocopherol to piglet tissues, colostrum, and milk: aspects of immune status of piglets. Res Vet Sci. 85:92–100.
PN-EN ISO 6867 2002. Pasze- oznaczenie zawartości witaminy E. Metoda wysokosprawnej chromatografii cieczowej - tokoferole w paszach.
Rettenmaier R, Schüep W. 1992. Determination of vitamins A and E in liver tissue. Int J Vitam Nutr Res. 62:312–317.
Rice-Evans CA, Miller NJ, Paganga G. 1996. Structure-antioxidant activity relationships of flavonoids and phenolic acids. Free Radic Biol Med. 20:933–956.
Sobota W, Flis M, Antoszkiewicz Z, Lipiński K, Zduńczyk Z. 2012. Effect of oat by-product antioxidants and vitamin E on the oxidative stability of pork from pigs fed diets supplemented with linseed oil. Arch Anim Nutr. 66:27–38.
Solberg R, Andresen JH, Escrig R, Vento M, Saugstad OD. 2007. Resuscitation of hypoxic newborn piglets with oxygen induces a dose-dependent increase in markers of oxidation. Pediatr Res. 62:559
Sosnowska A, Kawačka M, Jacyno E, Kołodziej-Skalska A, Kamyczek M, Matysiak B. 2011. Effect of dietary vitamins E and C supplementation on performance of sows and piglets. Acta Agric Scand A. 61:196–203.
Surai PF. 2014. Polyphenol compounds in the chicken/animal diet: from the past to the future. J Anim Physiol Anim Nutr (Berl). 98:19–31.
Szymańska E. 2012. Influence of specialization on economic results of pig farms. Acta Sci Pol. 11:65–76.
Tan C, Wei H, Sun H, Ao J, Long G, Jiang S, Peng J. 2015. Effects of dietary supplementation of oregano essential oil to sows on oxidative stress status, lactation feed intake of sows, and piglet performance. BioMed Res Int. 2015:1–9.
Torres JL, Varela B, García MT, Carilla J, Matito C, Centelles JJ, Cascante M, Sort X, Bobet R. 2002. Valorization of grape (Vitis vinifera) byproducts. Antioxidant and biological properties of polyphenolic fractions differing in procyanidin composition and flavonol content. J Agric Food Chem. 50:7548–7555.
Wijtten PJ, van der Meulen J, Verstegen MW. 2011. Intestinal barrier function and absorption in pigs after weaning: a review. Br. J. Nutr. 105:967–981.
Verhelst R, Schroyen M, Buys N, Niewold T. 2014. Dietary polyphenols reduce diarrhea in enterotoxigenic Escherichia coli (ETEC) infected post-weaning piglets. Livest Sci. 160:138–140.
Viveros A, Chamorro S, Pizarro M, Arija I, Centeno C, Brenes A. 2011. Effects of dietary polyphenol-rich grape products on intestinal microflora and gut morphology in broiler chicks. Poult Sci. 90:566–578.
Zhang HJ, Jiang XR, Mantovani G, Valdez Lumbreras AE, Comi M, Alborali G, Savoini G, Dell’Orto V, Bontempo V. 2014. Modulation of plasma antioxidant activity in weaned piglets by plant polyphenols. Ital J Anim Sci. 13:3242.
Zhong R-Z, Zhou D-W. 2013. Oxidative stress and role of natural plant derived antioxidants in animal reproduction. J Integr Agric. 12:1826–1838.