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Research article

# Inclusion of pistachio blanks in diets for weanling pigs has limited impact on growth performance and blood characteristics

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ABSTRACT

An experiment was conducted to test the hypothesis that pistachio blanks can be used as a fiber source in diets for weanling pigs. A total of 80 barrows and 80 gilts [initial body weight = 5.73 ± 0.33 kg] were randomly allotted to 4 dietary treatments using a randomized complete block design with initial body weight as the block. There were 2 barrows and 2 gilts in each pen and 10 replicate pens per treatment. The control diet contained mainly corn and soybean meal. Three additional diets were formulated to contain 50, 75, or 100 g/kg pistachio blanks at the expense of corn. Average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F) were calculated for phase 1 (day 1–21), phase 2 (day 22–42), and for the overall experimental period. Blood samples were collected and analyzed at the end of phases 1 and 2. Fecal samples were collected in phase 2 and analyzed for dry matter. Data were analyzed using a model that included diet as a fixed variable and block as a random variable. Polynomial contrasts were used to test linear and quadratic effects of increasing pistachio blanks in diets. Phase 1 results indicated that ADG, ADFI, G:F, and final body weight did not differ among dietary treatments. During phase 2, ADG, ADFI, and G:F were also not affected by diet and final body weight was not different among treatments. Overall growth performance from d 1–42 was not influenced by dietary treatments with the exception that there was a tendency (quadratic, $P = 0.097$) for ADG to be reduced for pigs fed the 50 g/kg pistachio blanks treatment but then increased as 75 or 100 g/kg pistachio blanks were used. Fecal dry matter tended (quadratic, $P = 0.051$) to be least in pigs fed the diet with 75 g/kg pistachio blanks compared with pigs fed the other diets. Concentrations of immunoglobulin G, immunoglobulin A, tumor necrosis factor alpha and peptide YY were not affected by dietary treatments at the end of either phase. It is concluded that pistachio blanks can be included in weanling pig diets by up to 100 g/kg without adversely affecting growth performance, immune markers, or diarrhea indicators.

## 1. Introduction

Pistachio blanks are agricultural co-products generated during the commercial processing of pistachios for human consumption. During standard pistachio processing, harvested nuts undergo cleaning, drying, sizing, and sorting to separate marketable, fully developed kernels from non-conforming material. Pistachio blanks are identified and separated through proprietary technologies

*Abbreviations:* ADFI, average daily feed intake; ADG, average daily gain; G:F, gain to feed ratio.

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based on size, density, and internal kernel development. Unlike regular pistachios, which contain a fully developed edible kernel, pistachio blanks consist primarily of hard outer shells enclosing undersized or unripe kernels. These products do not meet commercial specifications for retail or industrial-grade pistachios and are, therefore, diverted into a separate co-product stream. Although the internal kernel is not fully developed, it retains measurable nutritional components, including insoluble dietary fiber (primarily lignocellulosic material from the shell), fatty acids, low levels of crude protein, and bioactive compounds such as polyphenols.

The fibrous structure of pistachio blanks results in an elevated concentration of lignocellulosic fiber whereas crude protein remains relatively low compared with fully developed kernels (Kim et al., 2026a). The presence of polyphenolic compounds may contribute to antioxidant or prebiotic properties (Cardullo et al., 2021).

As pistachio production continues to expand in the United States, increasing volumes of pistachio co-products, including blanks, are generated annually (Kim et al., 2024; 2026b) and the annual production of pistachio blanks is believed to be between 50,000 and 100, 000 metric tons. Due to their composition, pistachio blanks may be used in animal feed applications, particularly in diets for pigs (Kim et al., 2026a). However, pistachio blanks may also be used as a substrate for bioenergy or compost production (Hazal et al., 2023).

Dietary fiber supplementation to pig diets may be advantageous during the post-weaning period, as it can stimulate gastrointestinal motility and promote microbial fermentation, resulting in a reduction in intestinal pH and synthesis of short-chain fatty acids, including butyrate that may positively impact the immune system of pigs (Jha et al., 2019; Han et al., 2023). Dietary fiber in starter diets for pigs may also increase the barrier function and inhibit or reduce growth of pathogenic bacteria and thereby reduce the risk of post-weaning diarrhea (Han et al., 2024). Indeed, inclusion of wheat bran in diets increased the height of intestinal villi and promoted synthesis of goblet cells (Vancamelbeke and Vermeire, 2017; Tang et al., 2022). The effectiveness of fiber in improving intestinal health depends on the type of fiber used (Ruiz et al., 2026), and fiber from pistachio shell powder down-regulated genes associated with intestinal inflammation when fed to rainbow trout indicating a positive impact on intestinal health (Abanikannda et al., 2024). Likewise, inclusion of up to 60 g/kg almond hulls, which is another high-fiber co-product from the commercial nut industry, in diets for weanling pigs tended to increase average daily gain (ADG) and gain to feed ratio (G:F) demonstrating that a high-fiber co-product from production of nuts can be beneficial in diets for weanling pigs (Ahammad et al., 2024). However, the inclusion level of dietary fiber in diets for weanling pigs is critical because excessive dietary fiber may reduce growth of pigs (Ruiz et al., 2026), but inclusion of up to 80 g/kg dietary fiber may improve growth performance during the post-weaning period (Flis et al., 2017). It is, therefore, possible that pistachio blanks will have similar beneficial effects on pig growth performance and recently, the metabolizable energy and the standardized ileal digestibility of amino acids in pistachio blanks were reported (Kim et al., 2026a). There are, however, no data for the inclusion of pistachio blanks in diets for weanling pigs and it is not known how pistachio blanks impact growth performance and

**Table 1**
Analyzed nutrient composition of ingredients, as-is basis.

| Item | Corn | Soybean meal | Pistachio blanks |
|---|---|---|---|
| Dry matter, g/kg | 876 | 887 | 943 |
| Ash, g/kg | 15 | 63 | 32 |
| Crude protein, g/kg | 74 | 463 | 63 |
| Acid-hydrolyzed ether extract, g/kg | 35 | 22 | 41 |
| Gross energy, kcal/kg | 3866 | 4119 | 4533 |
| Total dietary fiber, g/kg | 13 | 20 | 803 |
| Soluble dietary fiber, g/kg | 2 | 3 | 70 |
| Insoluble dietary fiber, g/kg | 11 | 17 | 734 |
| Polyphenols, μ/g[a] | - | - | 15,067 |
| Indispensable amino acids, g/kg | | | |
| Arginine | 3.7 | 33.0 | 13.0 |
| Histidine | 2.4 | 12.6 | 1.2 |
| Isoleucine | 3.0 | 22.9 | 2.0 |
| Leucine | 10.2 | 36.4 | 3.2 |
| Lysine | 2.7 | 29.1 | 3.2 |
| Methionine | 1.6 | 6.2 | 0.7 |
| Phenylalanine | 4.1 | 24.3 | 2.2 |
| Threonine | 2.9 | 17.7 | 1.7 |
| Tryptophan | 0.5 | 4.9 | 0.3 |
| Valine | 3.9 | 23.6 | 2.8 |
| Total | 35.1 | 210.7 | 30.3 |
| Dispensable amino acids, g/kg | | | |
| Alanine | 6.1 | 20.1 | 2.6 |
| Aspartic acid | 5.8 | 52.2 | 6.9 |
| Cysteine | 1.7 | 6.2 | 0.9 |
| Glutamic acid | 6.0 | 85.5 | 8.5 |
| Glycine | 3.0 | 19.3 | 2.2 |
| Proline | 7.3 | 23.1 | 3.6 |
| Serine | 3.7 | 19.4 | 2.2 |
| Tyrosine | 2.5 | 17.1 | 1.3 |
| Total | 36.1 | 242.9 | 28.2 |
| Total amino acids | 71.2 | 453.6 | 58.5 |

[a] Total polyphenols are expressed as gallic acid equivalents. The value is an average of 3 separate analyses.

immunity of newly weaned pigs, but based on previous work with fiber in diets for weanling pigs, we hypothesized that up to 100 g/kg pistachio blanks can be included in diets for weanling pigs without negatively affecting growth performance or immunity.

## 2. Materials and methods

All animal procedures were approved by the Institutional Animal Care and Use Committee at the University of Illinois, Urbana, IL, USA, before the experiment was initiated. Pigs were the offspring of Line 800 males mated to Camborough females (Pig Improvement Company, Henderson, TN, USA). Pigs were farrowed at the University of Illinois Swine Research Center (Champaign, IL, USA) and weaned at approximately 20 days of age. At weaning, pigs were moved to a nursery facility at the University of Illinois Swine Research Center (Urbana, IL, USA) and allotted to experimental diets beginning immediately after weaning. Pistachio blanks were procured from The Wonderful Company (Los Angeles, CA, USA); whey powder was procured from Prairie Farms Dairy Inc. (Edwardsville, IL, USA); soybean meal was procured from Solae LLC (Gibson City, IL, USA); and enzyme treated soybean meal was procured from Hamlet

**Table 2**
Ingredient and nutrient compositions of diets.

| Item | Phase 1 | | | | Phase 2 | | | |
|---|---|---|---|---|---|---|---|---|
| | | Pistachio blanks, g/kg | | | | Pistachio blanks, g/kg | | |
| Ingredients, g/kg | Control | 50 | 75 | 100 | Control | 50 | 75 | 100 |
| Ground corn | 482.1 | 434.3 | 411.4 | 388.6 | 598.1 | 550.3 | 527.4 | 504.6 |
| Soybean meal, dehulled | 190 | 190 | 190 | 190 | 290 | 290 | 290 | 290 |
| Pistachio blanks | - | 50 | 75 | 100 | - | 50 | 75 | 100 |
| Enzyme treated soybean meal | 90 | 90 | 85 | 82.5 | 50 | 47.5 | 45 | 42.5 |
| Spray-dried protein plasma | 30 | 30 | 30 | 30 | - | - | - | - |
| Soybean oil | 25 | 25 | 25 | 25 | 30 | 30 | 30 | 30 |
| Whey powder | 150 | 150 | 150 | 150 | - | - | - | - |
| $_{L}$- Lys·HCl, 780 g/kg Lys | 3.3 | 3.4 | 3.6 | 3 | 2.8 | 2.9 | 3.1 | 3.2 |
| $_{DL}$-Methionine, 998 g/kg | 1.5 | 1.6 | 1.7 | 1.8 | 1 | 1.1 | 1.2 | 1.3 |
| $_{L}$-Threonine, 998 g/kg | 0.6 | 0.7 | 0.8 | 0.9 | 0.6 | 0.7 | 0.8 | 0.9 |
| Dicalcium phosphate | 7.5 | 8 | 8 | 8 | 10 | 10 | 10 | 10 |
| Limestone | 11 | 10.5 | 10.5 | 10.5 | 8.5 | 8.5 | 8.5 | 8.5 |
| Vitamin-mineral premix[a] | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Salt | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Analyzed composition, g/kg | | | | | | | | |
| Dry matter | 885 | 888 | 885 | 877 | 874 | 869 | 860 | 858 |
| Crude protein | 221 | 200 | 195 | 213 | 203 | 207 | 194 | 192 |
| Total dietary fiber | 111 | 145 | 161 | 178 | 141 | 175 | 191 | 208 |
| Soluble dietary fiber | 18 | 21 | 22 | 23 | 22 | 25 | 26 | 27 |
| Insoluble dietary fiber | 92 | 124 | 140 | 155 | 119 | 150 | 165 | 181 |
| Indispensable amino acids | | | | | | | | |
| Arginine | 13 | 11 | 11 | 13 | 13 | 12 | 12 | 12 |
| Histidine | 6 | 5 | 5 | 6 | 6 | 5 | 5 | 5 |
| Isoleucine | 10 | 9 | 9 | 10 | 9 | 9 | 8 | 8 |
| Leucine | 19 | 18 | 17 | 19 | 17 | 17 | 16 | 16 |
| Lysine | 15 | 14 | 14 | 16 | 15 | 14 | 14 | 13 |
| Methionine | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Phenylalanine | 10 | 10 | 9 | 10 | 10 | 10 | 10 | 9 |
| Threonine | 10 | 9 | 9 | 10 | 9 | 9 | 8 | 8 |
| Tryptophan | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Valine | 11 | 11 | 10 | 11 | 10 | 10 | 9 | 9 |
| Total | 100 | 94 | 92 | 101 | 94 | 91 | 89 | 87 |
| Dispensable amino acids | | | | | | | | |
| Alanine | 11 | 10 | 10 | 10 | 10 | 10 | 10 | 9 |
| Aspartic acid | 22 | 20 | 20 | 22 | 20 | 20 | 19 | 19 |
| Cysteine | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 |
| Glutamic acid | 38 | 36 | 34 | 37 | 37 | 36 | 35 | 34 |
| Glycine | 8 | 7 | 7 | 8 | 8 | 8 | 8 | 8 |
| Proline | 12 | 11 | 11 | 12 | 12 | 11 | 11 | 11 |
| Serine | 9 | 9 | 8 | 9 | 9 | 8 | 8 | 8 |
| Tyrosine | 7 | 7 | 6 | 7 | 7 | 7 | 6 | 6 |
| Total | 111 | 103 | 100 | 109 | 106 | 102 | 100 | 97 |
| Total amino acids | 211 | 197 | 192 | 210 | 200 | 193 | 188 | 184 |

[a] Provided the following quantities of vitamins and micro-minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,136 IU; vitamin $D_3$ as cholecalciferol, 2208 IU; vitamin E as $_{DL}$-alpha tocopheryl acetate, 66 IU; vitamin K as menadione dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride,0.24 mg; vitamin $B_{12}$, 0.03 mg; $_{D}$-pantothenic acid as $_{D}$-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese hydroxychloride; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc hydroxychloride.

Protein (Findlay, OH, USA). Locally grown corn was obtained from the University of Illinois Feed Mill (Urbana, IL, USA), and spray-dried plasma protein (American Protein Corporation LLC, Ankeny, IA, USA) was also included in phase 1 diets (Table 1). The same batches of all ingredients were used in all diets within each phase (Table 2).

### 2.1. Diets, animals, and experimental design

A two-phase feeding program was used with day 1–21 as phase 1 and day 22–42 as phase 2. A total of 160 newly weaned pigs with an initial body weight of 5.73 ± 0.33 kg were used in a randomized complete block design with 10 blocks of 16 pigs per block. Within each block, pigs were randomly assigned to 4 dietary treatments using the Experimental Animal Allotment Program (Kim and Lindemann, 2007), and for each treatment, there were 10 replicate pens with 2 barrows and 2 gilts in each pen. A control diet based on corn and soybean meal was formulated, and 3 additional diets were formulated by including 50, 75, or 100 g/kg pistachio blanks primarily at the expense of corn and with adjustments of inclusion of crystalline amino acids. All diets in both phases were formulated to meet current nutrient requirements for weanling pigs (NRC, 2012). Metabolizable energy and standardized ileal digestibility of amino acids in pistachio blanks were determined in a previous experiment (Kim et al., 2026a) and these values were used in diet formulations.

Pigs were housed in pens (1.2 × 1.4 m) in an environmentally controlled barn. Floors were fully slatted with plastic coating. A 4-hole feeder and a nipple drinker were installed in each pen. Temperature, humidity, lighting, feeder and water space were identical for all pens. The barn had a negative pressure ventilation system and had lights turned on at all times. Barn temperatures were 30 °C in week 1 post-weaning, 28 °C in week 2, 26 °C in week 3, 24 °C in week 4, and 22 °C in weeks 5 and 6 post-weaning. Municipal water for human consumption was sourced from the city of Champaign (IL, USA).

### 2.2. Sample and data collection

Individual pig weights were recorded at the beginning of the experiment, on day 21, and at the end of the 42-day experiment. Daily feed allotments were recorded and the weight of feed left in the feeders was recorded on day 21 and on the last day of the experiment to calculate feed consumption. Feces were collected via anal stimulation on day 22, 28, 35, and 42 from the same two pigs in each pen for fecal dry matter analysis. Fecal samples were dried at 57 ºC in a forced air oven for 2 h, and the ratio of dried to wet fecal weight was used to determine fecal dry matter. The determined dry matter on the 4 collection days was then averaged within pen and treatment.

Two blood samples were collected on days 21 and 42 from the jugular vein of one pig in each pen whose body weight was closest to the pen average on day 21. Within each pen, the same pig was bled on the two bleeding days. One blood sample was collected in a vacutainer for collection of serum, and another blood sample was collected in a vacutainer containing ethylenediaminetetraacetic acid for harvest of plasma. Both blood samples were centrifuged at 4000 × g at 4 °C for 13 min. Serum and plasma were recovered and stored at −20 °C until analysis. Serum samples were analyzed for immunoglobulin G and immunoglobulin A using enzyme-linked immunosorbent assay kits according to the recommendations from the manufacturer (Bethyl Laboratories Inc., Montgomery, TX, USA). Plasma samples were analyzed for peptide YY and tumor necrosis factor- alpha using enzyme-linked immunosorbent assay kits according to the recommendations from the manufacturer (Phoenix Pharmaceuticals Inc., Burlingame, CA, USA, and R&D Systems, Inc., Minneapolis, MN, USA, respectively).

### 2.3. Chemical analysis

Samples of corn, soybean meal, and pistachio blanks were analyzed in duplicate for concentrations of gross energy using a bomb calorimeter (Model 6400, Parr Instruments, Moline, IL, USA), and nitrogen was analyzed in diets and ingredients by combustion (method 990.03; AOAC Int., 2019) using a LECO FP628 analyzer (LECO Corp., Saint Joseph, MI, USA) with the subsequent calculation of crude protein as nitrogen × 6.25. Dry matter was also analyzed in diet and ingredient samples by oven drying at 135 °C for 2 h (method 930.15, AOAC Int., 2019) and ingredient samples were also analyzed for dry ash (method 942.05; AOAC Int., 2019). All ingredient samples were analyzed for insoluble dietary fiber and soluble dietary fiber according to method 991.43 (AOAC Int., 2019) using the Ankom$^{TDF}$ Dietary Fiber Analyzer (Ankom Technology, Macedon, NY, USA). Total dietary fiber was calculated as the sum of insoluble and soluble dietary fiber. All ingredient samples were also analyzed for acid-hydrolyzed ether extract using the acid hydrolysis filter bag technique (Ankom HCl Hydrolysis System; Ankom Technology, Macedon, NY, USA) followed by crude fat extraction using petroleum ether (AnkomXT15 Extractor; Ankom Technology, Macedon, NY, USA). All diet and ingredient samples were analyzed for amino acids [method 982.30 E (a, b, c); AOAC Int., 2019] at the University of Missouri Experiment Station (Columbus, MO, USA) on a Hitachi Amino Acid analyzer (Model No. L8800; Hitachi High Technologies America, Inc., Pleasanton, CA, USA). Total polyphenols in pistachio blanks were analyzed as gallic acid equivalents (method 2017.13; AOAC Int., 2019).

### 2.4. Calculation and statistical analysis

Data for growth performance were summarized at the conclusion of the experiment to calculate ADG, average daily feed intake (ADFI), and G:F for each pen and treatment. Normality of residuals and homogeneity of variance were verified using the UNIVARIATE procedure (SAS Inst. Inc., 2016). Outliers were identified as values that deviated from the 1st or 3rd quartiles by more than 3 times the interquartile range using Internally Studentized Residuals (Tukey, 1977). However, no outliers were detected. All data were analyzed using the PROC MIXED of SAS with the pen as the experimental unit. The model included diet as fixed effect and block and pen within block were the random effects. Statistical significance was considered at $P < 0.05$ and tendency was considered at $0.05 \leq P < 0.10$. A contrast statement was used to determine effects of pistachio blanks on response variables.

## 3. Results

All pigs remained healthy throughout the experiment and readily consumed their assigned diets. Phase 1 results indicated that ADG, ADFI, G:F, and final body weight did not differ among treatments (Table 3). Average daily gain, ADFI, G:F, and final body weight in phase 2 were also not influenced by dietary treatments. Increasing pistachio blanks in phase 2 diets tended (quadratic, $P < 0.10$) to increase fecal DM to a maximum of 265.6 g/kg. Overall ADG for the entire 42-day experiment tended to decrease (quadratic, $P < 0.10$) when 50 g/kg pistachio blanks were used, but then increased if 75 or 100 g/kg were included in the diets.

At the end of phase 1, concentrations of immunoglobulin G, immunoglobulin A, tumor necrosis factor-α, and peptide YY were not affected by dietary treatments (Table 4). At the end of phase 2, serum concentrations of immunoglobulin G, immunoglobulin A, tumor necrosis factor-α, and peptide YY were also not influenced by dietary treatments.

## 4. Discussion

The analyzed nutrient composition of pistachio blanks, corn, and soybean meal used in the experiment was in agreement with expected values and confirmed that pistachio blanks is a high fiber ingredient as has been previously reported (Kim et al., 2026a). Pistachio blanks consist of ground pistachio shells, unripe nuts, branches, and leaves and contain mostly insoluble dietary fiber (Kim et al., 2026a). High-fiber co-products generally have lower nutritional value than corn and soybean meal because their high dietary fiber content is resistant to enzymatic hydrolysis in the small intestine and, consequently, is poorly digested by pigs (Bindelle et al., 2008; Jha et al., 2019). However, despite the high amount of dietary fiber in pistachio blanks, recent data indicate that the metabolizable energy in pistachio blanks is not different from that in corn because although the apparent total tract digestibility of gross energy was less in pistachio blanks than in corn, there was more gross energy in the pistachio blanks (Kim et al., 2026a).

Use of pistachio blanks instead of corn, therefore, does not reduce metabolizable energy in the diet. Inclusion of 80–100 g/kg of dietary fiber from oat hulls to diets for newly weaned pigs may improve intestinal dry matter and concentrations of volatile fatty acids in the gastro-intestinal tract (Hulshof et al., 2025). Pistachio blanks included by 50–100 g/kg provide 40–80 g/kg total dietary fiber to the diets, which is within the range of fiber inclusions that have been reported to be beneficial in diets for weanling pigs (Flis et al., 2017). Recently, inclusion of 25 g/kg total dietary fiber from almond shells, up to 30 g/kg total dietary fiber from almond hulls, or up to 80 g/kg total dietary fiber from pistachio shell powder were demonstrated to not reduce growth performance of weanling pigs (Ahammad et al., 2024; Kim et al., 2026b; Ruiz et al., 2026). However, no data have been published for addition of dietary fiber from pistachio blanks to diets for weanling pigs, but the hypothesis that pistachio blanks may be beneficial during the immediate post-weaning period was tested in the current experiment.

### *4.1. Growth performance*

The observation that inclusion of pistachio blanks in the diet did not affect overall growth performance with the exception of a tendency for reduced ADG by pigs fed the diet with 50 g/kg pistachio blanks indicated that under the conditions of this experiment,

**Table 3**
Growth performance and fecal dry matter of weanling pigs fed experimental diets.[a].

| Item | Control | Pistachio blanks, g/kg | | | SEM | P-value | |
|---|---|---|---|---|---|---|---|
| | | 50 | 75 | 100 | | Linear | Quadratic |
| Phase 1, d 1–21 | | | | | | | |
| Initial body weight | 5.58 | 5.73 | 5.74 | 5.74 | 0.09 | 0.117 | 0.429 |
| ADG[b], kg | 0.17 | 0.14 | 0.15 | 0.16 | 0.01 | 0.707 | 0.184 |
| ADFI[b], kg | 0.28 | 0.27 | 0.27 | 0.28 | 0.01 | 0.865 | 0.597 |
| G:F[b], kg per kg | 0.60 | 0.53 | 0.55 | 0.59 | 0.05 | 0.774 | 0.208 |
| Final body weight, kg | 9.11 | 8.76 | 8.93 | 9.17 | 0.31 | 0.957 | 0.309 |
| Phase 2, d 22–42 | | | | | | | |
| ADG, kg | 0.55 | 0.49 | 0.53 | 0.53 | 0.02 | 0.421 | 0.142 |
| ADFI, kg | 0.68 | 0.69 | 0.70 | 0.69 | 0.04 | 0.616 | 0.725 |
| G:F, kg per kg | 0.84 | 0.74 | 0.78 | 0.77 | 0.05 | 0.271 | 0.232 |
| Final body weight, kg | 20.74 | 19.14 | 20.12 | 20.23 | 0.70 | 0.584 | 0.117 |
| Fecal dry matter[c], g/kg | 274.2 | 246.7 | 233.0 | 265.6 | 13.1 | 0.314 | 0.051 |
| Overall, d 1–42 | | | | | | | |
| ADG, kg | 0.36 | 0.32 | 0.34 | 0.35 | 0.02 | 0.454 | 0.097 |
| ADFI, kg | 0.48 | 0.47 | 0.48 | 0.48 | 0.02 | 0.716 | 0.724 |
| G:F, kg | 0.76 | 0.68 | 0.72 | 0.72 | 0.03 | 0.283 | 0.125 |

[a] Each least square mean represents 10 observations.
[b] ADG, average daily gain; ADFI, average daily feed intake; G:F, gain to feed ratio.
[c] Data are averages of dry matter determined on days 22, 28, 35, and 42 post-weaning.

**Table 4**
Blood characteristics of weanling pigs fed experimental diets at the conclusion of each phase.[a]

| Item | Control | Pistachio blanks, g/kg | | | SEM | P-value | |
|---|---|---|---|---|---|---|---|
| | | 50 | 75 | 100 | | Linear | Quadratic |
| D 21 | | | | | | | |
| Immunoglobulin G, mg/mL | 11.80 | 13.88 | 15.45 | 11.40 | 1.73 | 0.767 | 0.122 |
| Immunoglobulin A, ng/mL | 70.02 | 71.88 | 81.24 | 65.14 | 8.48 | 0.982 | 0.378 |
| Tumor necrosis factor-alpha, ng/mL | 146.39 | 143.87 | 155.03 | 160.68 | 12.81 | 0.337 | 0.539 |
| Peptide YY, ng/mL | 1.15 | 1.15 | 1.17 | 1.09 | 0.11 | 0.778 | 0.698 |
| D 42 | | | | | | | |
| Immunoglobulin G, mg/mL | 14.21 | 13.60 | 16.54 | 13.39 | 1.36 | 0.907 | 0.550 |
| Immunoglobulin A, ng/mL | 127.39 | 105.23 | 125.17 | 110.37 | 14.98 | 0.563 | 0.720 |
| Tumor necrosis factor-alpha, ng/mL | 94.37 | 93.58 | 90.58 | 96.03 | 9.51 | 0.992 | 0.781 |
| Peptide YY, ng/mL | 1.36 | 1.52 | 1.23 | 1.24 | 0.21 | 0.588 | 0.522 |

[a] Each least square mean represents 10 observations.

weanling pigs could utilize up to 100 g/kg pistachio blanks in the post-weaning diets. All diets were formulated to meet requirements for standardized ileal digestible amino acids, which likely contributed to the lack of difference in growth performance among diets (Jaworski et al., 2014). The absence of a reduction in feed intake or feed efficiency among treatments indicates that palatability or nutrient digestibility were not impaired by inclusion of pistachio blanks in diets. Similar results were reported when 20–100 g/kg of total dietary fiber from other fibrous co-products such as almond hulls, almond shells, copra meal, or palm kernel meal were included in diets for weanling pigs (Jaworski et al., 2014; Ahammad et al., 2024; Ruiz et al., 2026), indicating that moderate levels of insoluble fiber can be tolerated without adverse effects on growth performance. Likewise, inclusion of 100 g/kg pecan hulls in diets for finishing pigs had no impact on growth performance (Flores et al., 2023). The fact that G:F was not negatively impacted by pistachio blanks confirms that metabolizable energy in pistachio blanks likely is close to that in corn. Indeed, recent data indicated that pistachio blanks contain 15.1 megajoule metabolizable energy per kg dry matter when included in diets for growing pigs (Kim et al., 2026a). Presumably, weanling pigs have less fermentative capacity than growing pigs, but despite this limitation, it appears that pistachio blanks are well utilized by pigs indicating a high fermentability of the fiber in pistachio blanks. Nevertheless, the tendency for a reduction in ADG for the overall experiment when pistachio blanks were included in the diets may indicate that despite the lack of differences in G:F among treatments, the metabolizable energy in pistachio blanks may be slightly less than in corn. It is also noted that the overall growth performance of pigs was slightly less than what is sometimes experienced in experiments with weanling pigs, which is likely because pigs had a low weaning weight and that antibiotic growth promoters or pharmaceutical levels of zinc and copper were not used. Likewise, except for 30 g/kg spray-dry plasma and 150 g/kg whey powder in phase 1 diets, no animal proteins were included in the diets.

### 4.2. *Fecal dry matter*

The observation that fecal dry matter tended to be less for pigs fed diets containing 50 or 75 g/kg pistachio blanks indicates increased fermentation in the hindgut of pigs fed these diets. Increased fecal water content is commonly associated with enhanced fermentation of fiber and synthesis of short-chain fatty acids, which can increase water influx into the large intestine (Jha and Berrocoso, 2016). However, all values for fecal dry matter were within the normal physiological range for weanling pigs (Warner et al., 2022), indicating that dietary treatment did not influence diarrhea in pigs, and no visible diarrhea was observed for any treatments. This observation is in agreement with data demonstrating that inclusion of up to 60 g/kg almond hulls in diets for weanling pigs does not change fecal scores (Ahammad et al., 2024).

### 4.3. *Blood characteristics*

The observation that serum concentrations of immunoglobulin G and immunoglobulin A, tumor necrosis factor-α, and peptide YY were not affected by the inclusion of pistachio blanks in the diet indicates that including up to 100 g/kg pistachio blanks in diets for weanling pigs were well tolerated. Immunoglobulin G and immunoglobulin A are commonly used markers for systemic and mucosal humoral immunity, respectively (Vidarsson et al., 2014), whereas tumor necrosis factor-α is a prototypical pro-inflammatory cytokine that indicates intestinal inflammation (Droessler et al., 2021). Because polyphenols have anti-inflammatory activities (Hussain et al., 2021) it was expected that tumor necrosis factor-α would decrease as pistachio blanks were included in the diets, but the fact that this was not observed indicates that there was an overall low disease pressure among pigs used in the experiment. Polyphenols are also expected to modulate the intestinal microbiota and enhance intestinal health (Anghel et al., 2024), which may have contributed to the quadratic response to inclusion of pistachio blanks that was observed for fecal dry matter. However, future experiments should be directed at directly determining the impact of pistachio blanks on the intestinal microbiome.

Peptide YY is secreted by enteroendocrine L-cells and its release can be stimulated by short-chain fatty acids produced during microbial fermentation of dietary fiber (Psichas et al., 2015). The lack of differences in plasma peptide YY among treatments indicates that the level and type of fiber provided by pistachio blanks were not sufficient to change gut hormone secretion or feed intake regulation. This agrees with the unchanged ADFI among treatments observed throughout the experiment. The absence of measurable change in immune and metabolic markers agrees with results from experiments evaluating inclusion of other high-fiber ingredients such as sugar beet pulp, soybean hulls, or almond hulls in weanling pig diets, where immune indicators and cytokine levels remained constant regardless of the level of fiber in the diet (Liu et al., 2022). Collectively, these results indicate that pistachio blanks do not exert negative effects on intestinal integrity or immune homeostasis in young pigs.

## 5. Conclusion

Inclusion of 50–100 g/kg pistachio blanks in diets for weanling pigs did not compromise overall growth performance, indicating that pistachio blanks can be used as a partial replacement for conventional feed ingredients without negative effects on weight gain or feed efficiency. Including pistachio blanks in diets for weanling pig by up to 100 g/kg also did not have negative effects on immune homeostasis in weanling pigs.

## CRediT authorship contribution statement

**Stein Hans H:** Writing – review & editing, Resources, Project administration, Funding acquisition, Conceptualization. **Yeonwoo Kim:** Writing – original draft, Resources, Investigation.

## Declaration of Competing Interest

The authors have no conflicts of interest.

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