Effect of dry- versus wet-autoclaving of spray-dried egg albumen compared with casein as protein sources on apparent nitrogen and energy balance, plasma urea nitrogen and glucose concentrations, and growth performance of neonatal swine

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Effect of dry- versus wet-autoclaving of spray-dried egg albumen compared with casein as protein sources on apparent nitrogen and energy balance, plasma urea nitrogen and glucose concentrations, and growth performance of neonatal swine

K. L. Watkins and T. L. Veum

Department of Animal Sciences, University of Missouri, Columbia 65211

**ABSTRACT:** Forty crossbred neonatal pigs with an average initial age of 4 d and BW of 2.16 kg were used in a 28-d experiment to evaluate the nutritional effects of autoclaving a commercial sugar-free, spray-dried egg albumen (EA) compared with casein. Basal diet protein sources were lactic acid casein and EA. Two more dietary treatments were made by replacing the EA with dry-autoclaved EA (DAEA) or wet-autoclaved EA (WAEA, EA and water mixed in a 1.0:1.2 ratio before autoclaving). The DAEA and WAEA were autoclaved at 121°C and 1.75 kg/cm² pressure for 30 min, and WAEA was oven-dried after autoclaving. Analyzed trypsin inhibitor units/mg of EA, DAEA, and WAEA were 535.0, 9.0, and 6.5, respectively. Pigs were fed the diets in gruel form to appetite in individual metabolism cages every 2 h during the experiment. Blood samples were taken on d 7, 14, and 21, and total urine and fecal grab-samples were collected from d 14 to 21 of the experiment. Response criteria were N and energy balance, plasma urea N (PUN) and glucose concentrations, and growth performance. The WAEA was a higher quality protein source for neonatal pigs than DAEA. Pigs fed the diet containing WAEA absorbed and retained more (P < 0.05) grams of N/d, had higher (P < 0.05) percentages of N and energy that were absorbed and retained/intake, had lower (P < 0.05) concentrations of PUN overall, and had higher (P < 0.05) ADG and G:F than pigs fed the diet containing DAEA. Most response criteria of pigs fed the diets containing DAEA or EA were not different, although pigs fed the diet containing DAEA had lower (P < 0.05) overall PUN concentrations, and pigs fed the diet containing EA had higher (P < 0.05) percentages of energy absorbed and retained/intake, and higher ADG and G:F than pigs fed the diet containing DAEA. Growth performance was not different for pigs fed the diets containing WAEA or casein. However, pigs fed the diet containing casein excreted less (P < 0.05) fecal N, retained more (P < 0.05) grams of N/d, had higher percentages of N absorbed and retained/intake, and had lower (P < 0.05) PUN concentrations overall than pigs fed the diet containing WAEA. In conclusion, WAEA was a higher quality protein source for neonatal pigs than DAEA or EA, whereas lactic casein was a higher quality protein source for neonatal pigs than EA, DAEA, or WAEA.

**Key words:** casein, energy and nitrogen balance, growth performance, neonatal swine, plasma urea nitrogen, spray-dried egg albumen

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INTRODUCTION

Spray-dried egg albumen (EA) is low in Zn, which has made EA the protein source of choice to determine the Zn requirement and the availability of Zn in protein sources for swine (Hankins et al., 1985a, b; Bo-
is more resistant to heat treatment and proteolysis in the digestive tract (Baumgärtner, 1957; Kassell, 1970; Green, 1975), and biotin supplementation is required to prevent a biotin deficiency when EA is the only protein source in diets for poultry (Eakin et al., 1940; Kratzer et al., 1988), swine (Cunha et al., 1946), mink (Wehr et al., 1980), and rats (György et al., 1941; Klevay, 1976).

The protease inhibitor content of EA is reduced by autoclaving the EA used in semipurified diets fed to poultry (Hempe and Savage, 1990) and swine (Hamilton et al., 1983; Hankins et al., 1985b; Bobilya et al., 1991). However, growth performance was lower for chicks fed diets containing dry-autoclaved EA than for chicks fed diets containing wet (rehydrated)-autoclaved EA (Hempe and Savage, 1990). Therefore, the objective of this experiment was to evaluate dry- vs. wet-autoclaving of EA, with casein as a positive control, in semipurified diets fed to neonatal swine. Response criteria were N and energy balance, plasma urea N (PUN) and glucose concentrations, and growth performance.

**MATERIALS AND METHODS**

The procedures and use of animals in this experiment were approved by the University of Missouri Animal Care and Use Committee.

**Animals and Housing**

Crossbred pigs (Yorkshire-Landrace sows × Duroc boars) were farrowed in an enclosed, heated, and ventilated farrowing building. At 2 d of age the pigs were injected with 100 mg of Fe as iron dextran, the needle teeth were clipped, and the males were castrated. At 3 d of age, a total of 40 pigs (24 barrows and 16 gilts) were weaned and transferred to individual stainless-steel metabolism cages (floor space: 0.31 m²) with drinkers, feeders, and woven wire floors in a heated and ventilated neonatal pig rearing room. Also on d 3, all the pigs were fed an animal protein-based sow milk replacer (Soweena, Merrick’s Inc., Middleton, WI) in liquid form (13% solids) to appetite every 2 h for 24 h to acclimate the pigs to the artificial feeding regimen that was used during the 21-d experiment. At 4 d of age and average BW of 2.16 ± 0.15, the pigs were allotted to the 4 dietary treatments by litter, sex, and BW. Temperature was maintained at about 32, 31, and 30 ± 1°C for wk 1 to 3, respectively.

**Dietary Treatments**

Protein sources for the 2 semi-purified basal diets (Table 1) were lactic acid casein (National Casein Co., Chicago, IL) and EA (M. G. Waldbaum Co., Wakefield, NE). Two additional dietary treatments were made by replacing the EA with dry-autoclaved EA (DAEA) or rehydrated, wet-autoclaved EA (WAEA). Before wet-autoclaving, EA and water were mixed in a 1.0:1.2 ratio, respectively. The DAEA and WAEA were placed in flat stainless-steel pans to a depth of about 5 cm and autoclaved in a laboratory sterilizer (Amsco model 2053, American Sterilizer Co., Erie, PA) at 121°C and 1.75 kg/cm² pressure for 30 min. After autoclaving, the WAEA cake was cut and chopped into pieces, dried in a forced-air oven at 55°C for 6 h, and reground in a hammer mill (Fitz Mill, model D, The Fitzpatrick Co., Chicago, IL) to pass a 2-mm screen. At feeding, all the diets were mixed with water to make a gruel mixture that had a diet:water ratio of 1:3, 1:2, or 1:1.5 for wk 1, 2, or 3, respectively. Each pig was hand-fed to appetite every 2 h from 0800 to 2200 h with additional water provided ad libitum in a separate cup.

Because the apparent and true ileal essential AA digestibilities of lactic acid casein for swine are high, averaging 95 and 99%, respectively, for growing swine (Kies et al., 1986; Chung and Baker, 1992; Nyachoti et al., 1997), the diet containing lactic casein in the current experiment exceeded the apparent and true ileal digestible AA requirements for swine from 3 to 5 kg of BW (NRC, 1998). The true ileal essential AA digestibilities of lactic casein also averaged about 98% for growing rats (Moughan and Rutherford, 1996; Rutherford and Moughan, 1998). The apparent and true ileal essential AA digestibilities of EA have not been determined for swine, although EA had a true protein digestibility of 98% and biological values of 95 to 100% for growing rats (Phillips et al., 1981; Eyre, 1983). Also, early weaned pigs fed diets containing EA had higher apparent ileal essential AA digestibilities than pigs fed the diet containing spray-dried porcine plasma (Schmidt et al., 2003), indicating that the diet containing EA in the present experiment also exceeded the apparent and true ileal AA requirements of pigs from 3 to 5 kg of BW.

Because the concentration of avidin in egg albumen is high (György and Rose, 1942), the diets in the present study were supplemented with 2.0 mg of biotin/kg of diet to prevent any possibility of a biotin deficiency. This was about 25 times the biotin requirement for neonatal and young pigs (Kopinski and Leibholz, 1989; NRC, 1998), and the same concentration of supplemental biotin that maximized growth of growing rats fed a diet containing EA as the only source of protein (Klevay, 1976).

**Measurements**

Pigs were weighed individually on d 0, 7, 14, and 21 of the experiment. Diet consumption was determined for each 7-d period, with feed consumption from d 14 to 21 corresponding to the 7-d fecal and urine collection period for N and energy balance. Casein and EA were analyzed for total AA concentrations (Benson and Patterson, 1971). Triplicate samples were hydrolyzed under N with 6 N HCl for 24 h at 110°C before AA analysis was performed by automated cation-exchange chromato-
Table 1. Ingredient and chemical composition (%) of air-dried basal diets, as-fed basis

<table>
<thead>
<tr>
<th>Item</th>
<th>Basal diet</th>
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<tr>
<td></td>
<td>Casein¹</td>
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<tr>
<td>Ingredient</td>
<td>22.35</td>
</tr>
<tr>
<td>Casein</td>
<td>22.35</td>
</tr>
<tr>
<td>Spray-dried egg albumen</td>
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</tr>
<tr>
<td>Glucose monohydrate</td>
<td>50.01</td>
</tr>
<tr>
<td>Corn oil</td>
<td>10.30</td>
</tr>
<tr>
<td>Dicalcium phosphate³</td>
<td>4.32</td>
</tr>
<tr>
<td>Vitamin and antibiotic premix⁴</td>
<td>0.75</td>
</tr>
<tr>
<td>Cellulose</td>
<td>1.00</td>
</tr>
<tr>
<td>Trace mineral premix⁵</td>
<td>0.25</td>
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<tr>
<td>Macromineral premixes⁶,⁷</td>
<td>1.82</td>
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<tr>
<td>Chronic oxide⁸</td>
<td>0.20</td>
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<tr>
<td>Chemical composition⁹,¹⁰</td>
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<tr>
<td>CP</td>
<td>19.68</td>
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<tr>
<td>Lys</td>
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<tr>
<td>Met + Cys</td>
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<tr>
<td>Thr</td>
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<tr>
<td>Trp</td>
<td>0.28</td>
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<tr>
<td>Val</td>
<td>1.36</td>
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<tr>
<td>Ile</td>
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<tr>
<td>Ca</td>
<td>1.22</td>
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<tr>
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<tr>
<td>Available P</td>
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<tr>
<td>K</td>
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<tr>
<td>Mg</td>
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<td>Na</td>
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<tr>
<td>Cl</td>
<td>0.31</td>
</tr>
<tr>
<td>ME, Mcal/kg</td>
<td>3.58</td>
</tr>
</tbody>
</table>

¹Lactic acid casein (National Casein Co., Chicago, IL) made one dietary treatment.
²Spray-dried egg albumen (EA, M.G. Waldbaum Co., Wakefield, NE) made another dietary treatment. Two more dietary treatments were made by replacing EA with dry-autoclaved EA (DAEA, autoclaved dry at 121°C and 1.75 kg/cm² pressure for 30 min) or wet-autoclaved EA (WAEA, with EA and water mixed in a 1.0:1.2 ratio, respectively. WAEA was autoclaved at 121°C and 1.75 kg/cm² pressure for 30 min, and dried at 55°C in a forced-air oven for 6 h).
³Dicalcium phosphate contained 22.0% Ca and 18.5% P.
⁴Vitamin and antibiotic premix provided per kilogram of diet: 6,600 IU of vitamin A acetate; 660 IU of vitamin D₃; 35.0 mg of vitamin E from dl-α-tocopheryl acetate; 15.0 mg of menadione sodium dime-thylhydrolino bisulphite; 9.0 mg of riboflavin; 66.0 mg of niacin; 39.0 mg of pantothenic acid from β-calcium pantothenate; 2.0 g of choline from choline chloride; 3.9 mg of thiamine from thiamine mononitrate; 4.5 mg of pyridoxine from pyridoxine HCl; 0.5 mg of biotin from β-biotin; 1.8 mg of folic acid; 660.0 mg of ascorbic acid; 70.0 µg of vitamin B₁₂; 165 mg of oxytetracycline HCl; and 220 mg of neomycin sulfate.
⁵Trace mineral premix provided per kilogram of diet: 225.0 mg of Fe from FeSO₄; 150.0 mg of Zn from ZnCO₃; 9.0 mg of Cu from CuSO₄; 5.0 mg of Mn from MnSO₄; 0.21 mg of I from KIO₃; and 0.22 mg of Se from Na₂SeO₃.
⁶Macronineral premix for the casein diet provided per kilogram of diet: 1.96 g of Na and 3.01 g of Cl from NaCl, 3.70 g of K from K₂CO₃, 0.30 g of Mg from MgCO₃ and 0.30 g of Mg from MgSO₄.
⁷Macronineral premix for the EA, DAEA, and WAEA diets provided per kilogram of diet: 1.21 g of K from K₂CO₃, 0.19 g of Mg from MgCO₃, and 0.19 g of Mg from MgSO₄.
⁸Chromic oxide was added as a nondigestible indicator to allow fecal grab samples during the collection period (18 to 25 d of age) to determine N and energy balance.
⁹Calculated mineral and ME composition of the diets, with the values for casein and corn oil from the NRC (1982) and the values for EA from Cotterill et al. (1978), including the minerals provided by dicalcium phosphate and the macromineral premixes.
percent availability of Lys, the Lys bound to 1-fluoro-2,4-dinitrobenzene (FDNB) is considered to be available Lys because free ε-amino groups of proteins react with FDNB to form a stable complex that is resistant to acid hydrolysis. The samples treated with FDNB were acid-hydrolyzed to determine the unavailable Lys concentration, with available Lys calculated by difference. The EA was also analyzed for biotin activity (Scheiner, 1966, 1985). All analyses were conducted with triplicate samples.

Blood samples (6 mL) were taken by anterior vena cava puncture from individual pigs after a 3-h fast (0800 to 1100 h) on d 7, 14, and 21 of the experiment. Blood samples were placed in plastic centrifuge tubes that contained 0.12 mL of saline with 6.0% neutralized EDTA per tube as an anticoagulant, and kept on ice until centrifugation (Beckman GPR, Arlington Heights, IL) at 3,000 × g for 10 min at 5°C. The plasma was decanted into 5-mL glass vials and stored at −20°C until the samples were deproteinized with 10% (wt/vol) trichloroacetic acid and analyzed for total glucose by the o-toluidine method (Sigma, 1980b), and for PUN by the diacyl monoxime method (Sigma, 1980a).

Nitrogen and energy balance were determined using 6 barrows/treatment from d 14 to 21 in the current experiment. Chromic oxide in the diets (0.05%) allowed fecal grab samples to be collected daily from individual pigs and frozen in plastic bags. Total daily urine collections were frozen in plastic bottles. About 5.0 mL of toluene and 5.0 mL of 6 N HCl were added to each urine collection bottle daily to prevent evaporation and N loss. Pooled fecal samples from each pig were freeze-dried and ground to pass a 2-mm screen (Wiley mill, Arthur H. Thomas, Philadelphia, PA). Triplicate samples of diet and duplicate samples of feces and urine were analyzed for N and DM (AOAC, 1980), and the analyzed values for dietary N were used to determine N balance. Chromic oxide concentrations of diet and fecal samples were determined with an atomic absorption spectrophotometer (model 2380, Perkin-Elmer Corp., Norwalk, CT). The GE content of the diet, fecal, and urine samples was determined with an oxygen bomb calorimeter (Parr Instrument Co., Moline, IL). To determine the GE content of urine, 50.0 mL of urine was mixed with 2.0 g of finely ground cellulose. The mixture was freeze-dried, reground with a mortar and pestle, and analyzed for GE. The GE value for cellulose was subtracted from the total to obtain the GE value for urine.

Statistical Analysis

All data were analyzed by ANOVA as a completely randomized design (Snedecor and Cochran, 1989) using the GLM procedure (SAS Inst. Inc., Cary, NC). Individual pigs were the experimental units. Treatment means were separated using the F-protected LSD test, with significance taken at P < 0.05.

RESULTS

Trypsin Inhibitor, Lys Availability, and Biotin Analyses of Egg Albumen Products

Mean values of trypsin inhibitor (inhibitor units/ mg of sample ± SD) for EA, DAEA, and WAEA were 535.0 ± 21.4, 9.0 ± 7.3, and 6.5 ± 2.9, respectively. The availability of Lys, estimated using the FDNB method, was 96, 88, and 97% for EA, DAEA, and WAEA, respectively. The biotin activity value of EA was 0.39 mg/kg.

Apparent N and Energy Balance

The ADFI during the balance period (18 to 25 d of age) was smaller (P < 0.05) for pigs fed the diet containing EA compared with pigs fed the diets containing DAEA, WAEA, or casein (Table 2). Therefore, pigs fed the diet containing EA had a smaller N intake (g/d, P < 0.05) than pigs fed the diets containing WAEA or casein, whereas the N intake of pigs fed the diet containing DAEA was not different from the other treatment groups.

Nitrogen absorption (g/d) was highest (P < 0.05) for pigs fed the diets containing casein or WAEA, which did not differ from each other, followed by EA, which did not differ from WAEA, and finally DAEA, which did not differ from EA. Fecal N excretion (g/d) was highest (P < 0.05) for pigs fed the diet containing DAEA, intermediate (P < 0.05) for pigs fed the diet containing WAEA, and least (P < 0.05) for pigs fed the diets containing casein or EA. However, urinary N excretion (g/d) was higher (P < 0.05) for pigs fed the diet containing EA than pigs fed the other diets. Nitrogen retention (g/d) was highest (P < 0.05) for pigs fed the diet containing casein, followed by pigs fed the diet containing WAEA (P < 0.05), with pigs fed the diets containing DAEA or EA retaining the least N (P < 0.05).

For percentage N digestibility (N absorbed/intake × 100), pigs fed the diet containing casein had a higher N digestibility (%) than pigs fed the diet containing WAEA, whereas the N digestibility (%) of pigs fed the diet containing EA did not differ from pigs fed the diets containing casein or WAEA (Table 2). However, pigs fed the diet containing DAEA had the lowest (% P < 0.05) N digestibility. For percent biological value (N retained/absorbed × 100), the diets containing casein or WAEA were not different, followed by the diet containing DAEA, which did not differ from WAEA, whereas the diet containing EA had the lowest (% P < 0.05) biological value compared with the other diets. For percent net N utilization (N retained/ intake × 100), pigs fed the diet containing casein had the highest (% P < 0.05) value, followed by pigs fed the diet containing WAEA (P < 0.05), with pigs fed the diets containing EA or DAEA having the lowest
For energy utilization, pigs fed the diet containing DAEA had lower (\(P < 0.05\)) percentages of DE (energy absorbed/intake) and ME (energy retained/intake) utilization than pigs fed the diets containing casein, EA, or WAEA that were not different in percentage of DE or ME utilization.

**PUN and Plasma Glucose**

At 11 d of age, pigs fed the diet containing casein had the lowest (\(P < 0.05\)) PUN concentrations, followed by pigs fed the diet containing DAEA, with pigs fed the diet containing EA having the highest (\(P < 0.05\)) PUN concentration. Overall (mean of d 11, 18, and 25), pigs fed the diet containing casein had the lowest (\(P < 0.05\)) PUN concentrations, followed sequentially (\(P < 0.05\)) with increasing concentrations of PUN in pigs fed the diets containing WAEA, DAEA, or EA, respectively.

For plasma glucose concentrations, there were no treatment differences at 11, 18, or 25 d of age, or for the overall treatment means. The overall experimental plasma glucose mean ± SE was 60.6 ± 3.3 (data not shown).

**Growth Performance**

Growth performance (ADFI, ADG, and G:F) of the pigs fed the diet containing WAEA was not different from that of the pigs fed the diet containing casein (Table 4). However, the ADG and G:F of pigs fed the diet containing DAEA were less (\(P < 0.05\)) than the ADG

<table>
<thead>
<tr>
<th>Item</th>
<th>EA</th>
<th>Dry-autoclaved EA</th>
<th>Wet-autoclaved EA</th>
<th>Casein</th>
<th>SEM</th>
<th>(P)-value</th>
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<td>6</td>
<td>6</td>
<td>6</td>
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<td></td>
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<tr>
<td>ADFI(^1)</td>
<td>171.4(^*)</td>
<td>192.8(^*)</td>
<td>196.8(^*)</td>
<td>195.5(^*)</td>
<td>5.9</td>
<td>0.014</td>
</tr>
<tr>
<td>N</td>
<td>5.39(^b)</td>
<td>5.71(^a)</td>
<td>6.30(^a)</td>
<td>6.15(^a)</td>
<td>0.20</td>
<td>0.021</td>
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<tr>
<td>Absorbed, g/d</td>
<td>4.86(^bc)</td>
<td>4.17(^c)</td>
<td>5.37(^ab)</td>
<td>5.79(^b)</td>
<td>0.24</td>
<td>&lt;0.001</td>
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<tr>
<td>Fecal, g/d</td>
<td>0.53(^c)</td>
<td>1.54(^a)</td>
<td>0.93(^b)</td>
<td>0.36(^c)</td>
<td>0.13</td>
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<tr>
<td>Retained, g/d</td>
<td>1.98(^a)</td>
<td>1.11(^b)</td>
<td>1.03(^b)</td>
<td>0.78(^b)</td>
<td>0.12</td>
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<tr>
<td>absorbed, %</td>
<td>90.2(^a)</td>
<td>73.0(^b)</td>
<td>85.3(^b)</td>
<td>94.2(^a)</td>
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<td>59.3(^a)</td>
<td>73.4(^b)</td>
<td>80.8(^ab)</td>
<td>85.1(^a)</td>
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<td>53.6(^a)</td>
<td>68.9(^b)</td>
<td>81.5(^a)</td>
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<td>Absorb/intake, %</td>
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<td>85.4(^b)</td>
<td>90.6(^a)</td>
<td>91.8(^a)</td>
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<td>Retained/intake,</td>
<td>88.3(^a)</td>
<td>83.4(^b)</td>
<td>88.6(^a)</td>
<td>90.2(^a)</td>
<td>1.2</td>
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</tr>
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</table>

\(^*\)Means within a row lacking a common superscript letter differ (\(P < 0.05\)).

\(^1\)A 21-d experiment that started with pigs that were 4 d of age.

For plasma glucose concentrations, there were no treatment differences at 11, 18, or 25 d of age, or for the overall treatment means. The overall experimental plasma glucose mean ± SE was 60.6 ± 3.3 (data not shown).

**Growth Performance**

Growth performance (ADFI, ADG, and G:F) of the pigs fed the diet containing WAEA was not different from that of the pigs fed the diet containing casein (Table 4). However, the ADG and G:F of pigs fed the diet containing DAEA were less (\(P < 0.05\)) than the ADG

<table>
<thead>
<tr>
<th>Item</th>
<th>EA</th>
<th>Dry-autoclaved EA</th>
<th>Wet-autoclaved EA</th>
<th>Casein</th>
<th>SEM</th>
<th>(P)-value</th>
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<td>10</td>
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<td>Plasma urea N, mg/100 mL</td>
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<td>11</td>
<td>16.3(^a)</td>
<td>5.9(^b)</td>
<td>6.2(^b)</td>
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<td>18</td>
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<td>16.6(^b)</td>
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<td>4.4(^c)</td>
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<td>25</td>
<td>15.6(^a)</td>
<td>12.8(^b)</td>
<td>7.0(^c)</td>
<td>5.1(^b)</td>
<td>0.9</td>
<td>&lt;0.001</td>
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<tr>
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<td>11.8(^b)</td>
<td>8.2(^b)</td>
<td>3.7(^c)</td>
<td>0.7</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

\(^a\)Means within a row lacking a common superscript letter differ (\(P < 0.05\)).

\(^1\)A 21-d experiment that started with pigs that were 4 d of age.
DISCUSSION

Wet (rehydrated)-autoclaved EA clearly was a higher quality protein source for neonatal pigs than DAEA, when both were made from the same commercial source of sugar-free EA. Pigs fed the diet containing WAEA absorbed and retained more grams of N/d, had higher percentages of apparent N and energy absorbed and retained, had lower concentrations of PUN at 18 and 25 d of age and overall, and had higher ADG and G:F than pigs fed the diet containing DAEA. The results with neonatal pigs in the current experiment are in agreement with another experiment in which the growth performance of chicks fed a semipurified diet containing WAEA was much higher than that of chicks fed the semipurified diet containing DAEA (Hempe and Savage, 1990).

Both wet- and dry-autoclaving in the current experiment were very effective in reducing the trypsin inhibitor activity in WAEA and DAEA to similar concentrations of 6.5 ± 2.9 and 9.0 ± 7.3 inhibitor units/mg of sample, respectively, compared with the high trypsin inhibitor activity in nonautoclaved EA of 535.0 ± 21.4 units/mg of sample. Therefore, trypsin inhibitor activity may be excluded as an explanation for the improvement in the response criteria for the pigs fed the diet containing WAEA compared with pigs fed the diet containing DAEA. The heat-protecting effect of wet-autoclaving in the current experiment is also shown by the higher FDNB-available Lys value for WAEA (97%) compared with the DAEA (88%). In another experiment, feeding rats a diet containing heat-damaged casein reduced pancreatic enzyme turnover rate, which also reduced protein digestion and N absorption compared with rats fed a diet containing nonheated casein (Percival and Schneeman, 1979).

Most response criteria for pigs fed the diets containing DAEA or EA were not different, although pigs fed the diet containing DAEA had lower overall PUN concentrations, and pigs fed the diet containing EA had higher percentages of energy absorbed and retained/intake and higher ADG and G:F than pigs fed the diet containing DAEA. The lower DE and ME utilization (%) by pigs fed the diet containing DAEA in the current experiment is associated with the low apparent digestibility of the heat-damaged DAEA in the small intestine. A large amount of the heat-damaged DAEA was excreted in the feces, which indicates a low rate of

Table 4. Effect of protein source and autoclaving of the spray-dried egg albumen (EA) on the growth performance of neonatal swine from 4 to 25 d of age1

<table>
<thead>
<tr>
<th>Item</th>
<th>EA</th>
<th>Dry-autoclaved EA</th>
<th>Wet-autoclaved EA</th>
<th>Casein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pigs, No./mean BW, kg</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>4 d of age</td>
<td>2.16</td>
<td>2.13</td>
<td>2.15</td>
<td>2.18</td>
</tr>
<tr>
<td>25 d of age</td>
<td>3.68b</td>
<td>3.36b</td>
<td>4.26b</td>
<td>4.49b</td>
</tr>
<tr>
<td>ADFI, overall g</td>
<td>125c</td>
<td>127bc</td>
<td>133bc</td>
<td>135c</td>
</tr>
<tr>
<td>ADG, overall g</td>
<td>73b</td>
<td>58g</td>
<td>101b</td>
<td>110b</td>
</tr>
<tr>
<td>G:F, overall g/kg</td>
<td>503c</td>
<td>457c</td>
<td>729c</td>
<td>815c</td>
</tr>
</tbody>
</table>

a–c Means within a row lacking a common superscript letter differ (P < 0.05).
1 A 21-d experiment that started with pigs that were 4 d of age.
microbial fermentation of the DAEA in the large intestine. Another experiment with chicks has shown that significant amounts of dietary energy are lost when heat-damaged proteins are fermented in the cecum and large intestine or excreted in the feces (Nesheim and Carpenter, 1967).

The low spray-drying temperature used to make commercial EA had little to no heat-damage effect on the EA as indicated by the high FDNB available-Lys value of 96% for EA. However, the high trypsin inhibitor activity that remained in the EA (535 ± 21.4 inhibitor units/mg) undoubtedly had a negative effect on the apparent digestion and absorption of protein and AA in the small intestine, resulting in a large flow of indigested protein from the small intestine into the large intestine. However, the low fecal excretion of N by pigs fed the diet containing EA indicates a high rate of microbial fermentation of the EA in the large intestine. Microbial fermentation of protein in the cecum and large intestine yields N products and AA that are absorbed as ammonia and do not have any nutritional value (Nesheim and Carpenter, 1967; Varnish and Carpenter, 1975; Moughan and Rutherford, 1996). This provides an explanation for the poor utilization of N by the pigs fed the diet containing EA in the present experiment. Pigs fed the diet containing EA had a much higher absorption of N from the large intestine than pigs in the other treatment groups. Because N absorbed from the large intestine has no nutritional value and is not utilized biologically, the pigs fed the diet containing EA had higher PUN concentrations than pigs fed the diets containing casein or WAEA. Growth performance and energy utilization and growth performance, and lower PUN concentrations overall than pigs fed the diet containing WAEA, indicating that casein was a higher quality protein for neonatal pigs than WAEA, DAEA, or EA. Other experiments also found that casein was a higher quality protein, with an apparent total-tract N digestibility for casein of 96% by neonatal pigs (Mateo and Veum, 1980a), and average apparent and true ileal essential AA digestibilities for casein of 95 and 99%, respectively, for growing swine (Kies et al., 1986; Chung and Baker, 1992).

In another experiment with neonatal pigs, raw liquid egg albumen was an unsatisfactory protein source based on ADG, diarrhea score, and N utilization (Pettigrew and Harmon, 1977), most likely due to the protease inhibitors present in the liquid egg albumen. In an experiment with chicks, growth performance was severely depressed when the reducing sugars in experimentally prepared egg albumen were not removed before autoclaving for only 10 min or longer compared with no autoclaving (Kelly and Scott, 1968). Also, in another experiment with growing rats, egg albumen with glucose added before autoclaving at 120°C for 60 min was poorly utilized because of the Maillard reaction products that formed, compared with a minor reduction in protein utilization when the egg albumen was sugar-free before autoclaving (Valle-Riestra and Barnes, 1970).

The N digestibilities and PUN concentrations of the pigs in the present experiment are within the range of values reported in other experiments where neonatal pigs were fed semipurified diets containing WAEA (Hankins et al., 1985a,b) or other protein sources (Sherry et al., 1978; Mateo and Veum, 1980a,b). The amount of diet fed in the present metabolism experiment was restricted to the amount that each individual pig would consume daily to prevent diet wastage, a diet-management technique commonly used in metabolism experiments (Pond et al., 1971). It is known that group feeding may stimulate diet consumption through an enhanced social interaction (Brumm and Gonyou, 2001), which was not possible in the present metabolism experiment or other experiments where neonatal pigs were housed individually in solid-walled metabolism cages (Sherry et al., 1978; Mateo and Veum, 1980a; Zamora and Veum, 1988). However, pigs fed the diets containing casein or WAEA in the present experiment doubled their BW, and the ADFI and ADG of the pigs on all the treatments were more than adequate to maintain a positive nutrient balance.

In conclusion, rehydrating the EA before wet-autoclaving reduced the amount of heat-damaged protein and the losses in Lys and protein quality compared with dry-autoclaving the EA. Neonatal pigs fed the diet containing WAEA had higher apparent N and energy utilization and growth performance, and lower PUN concentrations than pigs fed the diets containing EA or DAEA. Growth performance and energy utilization of pigs fed the diets containing casein or WAEA were
not different, although pigs fed the diet containing casein had higher apparent N utilization and lower PUN concentrations than pigs fed the other diets. Therefore, high quality casein may be the protein of choice for use in semi-purified diets for neonatal pigs in most experiments. However, EA may be the protein of choice when semi-purified diets with a low trace mineral content are required. Before autoclaving, the EA should be rehydrated and autoclaved wet to produce a high-quality protein that is closer to casein in quality.

**LITERATURE CITED**


Watkins and Veum


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