Bioavailability of Zinc in Ground Beef

Audra E. Hortin, George Oduho, Yanming Han, Peter J. Bechtel1, and David H. Baker2

Department of Animal Sciences and Division of Nutritional Sciences, University of Illinois, Urbana 61801

ABSTRACT: Based on zinc uptake in chick tibia, Zn bioavailability in cooked ground beef was equal to that of Zn in an inorganic standard (ZnSO₄), whether Zn supplements were added to a soy-concentrate diet containing phytate or to a phytate-free egg-white diet. With both diet types, total tibia Zn was a linear (P<.01) function of supplemental Zn intake from ZnSO₄, but the slope of the linear regression line was twice as great for the egg-white diet as for the soy-concentrate diet that contained phytate. At 10 mg/kg of supplemental Zn, freeze-dried ground beef produced the same tibia Zn concentration (and total Zn content) as that obtained with ZnSO₄. The results suggest that the relative bioavailability of Zn in cooked ground beef is as great as that in ZnSO₄, whether consumed in diets with or in those without phytate.

Key Words: Bioavailability, Zinc, Ground Beef, Bones, Phytic Acid

Introduction

Zinc is an important micronutrient in the human diet, and many people of all ages in the United States are marginal in terms of Zn adequacy (Sandstead, 1973; Welsh and Marston, 1983). The marginal state is due not only to a low intake of Zn-containing foods, but also to consumption of diets containing Zn antagonists, such as phytate and soluble fiber (O'Dell, 1969; Underwood, 1977; Welsh and Marston, 1983; Solomons and Cousins, 1984; Moser-Veillon, 1990).

The bioavailability of Zn in beef and pork is very high (Brown et al., 1985; Gallaher et al., 1988; Hortin et al., 1991), whereas that from soy protein isolates and other processed soy products is much lower (O'Dell et al., 1972; Erdman and Forbes, 1981; Wedekind et al., 1992). Phytate binding may be responsible for the low Zn bioavailability in plant-source foods (Erdman and Forbes, 1981; Baker and Halpin, 1988).

The objective of the work reported here was to determine Zn bioavailability in cooked ground beef relative to that furnished by an accepted inorganic standard (i.e., ZnSO₄). Previous work of this type has been done with rats (Brown et al., 1985), using ZnCO₃ as a standard. Because ZnCO₃ is not a commonly used Zn supplement for either animals or humans, and because coprophagy in rats (Barnes and Fiala, 1958; Williams and Senior, 1985) is a potential confounding factor in Zn bioavailability assessment, chicks fed ZnSO₄ as the standard were used herein.

Materials and Methods

Hamburger Processing

All-beef ground beef patties were processed at the University of Illinois Meat Science Laboratory. Ninety-percent beef trim was coarsely ground through a 2.5-cm plate in a Hobart grinder (Model A52). Fat content was adjusted to 15%. Patties weighing 114.5 g were formed using an Accupat food-shaper (Model 3AP, Bridge Machine, Palmyra, NJ) and then were quick-frozen in a -34°C blast freezer and held for subsequent cooking and analyses.

The ground beef patties were uniformly cooked on stainless steel trays in a Southbend convection oven at
a temperature of 165°C. Patties were cooked to an internal temperature of approximately 75°C. Internal temperature was determined using a thermocouple attached to a temperature recording device. After cooking, patties were weighed and then stored frozen at -34°C. The patties were crumbled and placed on large stainless steel trays, after which they were freeze-dried for 24 h. Weights were taken after freeze-drying. The patties were then ground twice in a Black & Decker Shortcut food processor (Model CFP10; Black & Decker, Shelton, CT) to a fine granular consistency.

Zinc analyses were performed after wet-ashing using HNO₃ and H₂O₂ (Wedekind and Baker, 1990); Zn concentration was measured by atomic absorption spectrophotometry (Model 306; Perkin-Elmer, Norwalk, CT). The freeze-dried ground beef patties contained 143 mg of Zn/kg.

**Animals and Diets**

Two experiments were conducted using male chicks from the cross of New Hampshire males and Columbian females. From hatching to d 7 posthatching, chicks in Exp. 1 were fed a 23% CP corn-soybean meal diet containing 120 mg of Zn/kg; in Exp. 2, a 20% CP egg-white diet (.32 mg of Zn/kg) was fed during this pretest period. On d 8 posthatching after an overnight fast, chicks were weighed and allotted to experimental groups so that each group had a similar average initial weight and weight distribution. Four replicate groups of four chicks were fed the experimental diets from 8 to 22 d posthatching. Diets and water were provided for ad libitum consumption. Chicks were kept on a 24-h constant-light schedule in heated, thermostatically controlled, stainless steel batteries with raised wire floors. Stainless-steel waterers and feeders were also used to minimize Zn contamination.

The basal diets (Table 1) were formulated to contain adequate amounts of all nutrients except Zn (NRC, 1984). They were analyzed for Zn by atomic absorption spectrophotometry. The unsupplemented soy-concentrate diet contained 14 mg of Zn/kg, well below the NRC (1984) suggested requirement of Zn for young chicks. It also contained .92% phytate (phytate analysis performed by Central Soya, Ft. Wayne, IN). The egg-white diet contained .32 mg of Zn/kg. Zinc sources were added to diets at the expense of dextrose. The supplemented Zn was provided as feed-grade ZnSO₄·H₂O (36% Zn; Southeastern Minerals, Bainbridge, GA) or from ground beef patties.

Upon termination of experiments, chicks were killed via cervical dislocation and tibias were quantitatively removed. Tibias were pooled by replicate, stripped of adhering tissue, and then dried at 105°C for 24 h, weighed, and dry-ashed at 600°C overnight. The ashed bones were then wet-ashed using HNO₃ and H₂O₂ (Wedekind and Baker, 1990). Zinc concentration was measured by atomic absorption spectrophotometry as described by Wedekind et al. (1992).

**Zinc Bioavailability Experiments**

Experiment 1 was conducted to determine the relative bioavailability of Zn in ground beef patties compared to a ZnSO₄ standard. Dietary levels of 0, 5, 10, and 15 mg of Zn/kg from ZnSO₄ were added to the Zn-deficient soy-concentrate diet (Table 1) at the expense of dextrose to construct a standard curve (total tibia Zn regressed on supplemental Zn intake). Sulfates of Zn in our chick bioassay system have been deemed to be the most highly bioavailable source of inorganic Zn; both feed-grade ZnSO₄·H₂O and reagent-grade ZnSO₄·7H₂O furnish bioavailable Zn twice as efficiently as ZnO (Wedekind and Baker, 1990; Wedekind et al., 1992). The standard curve was used to ascertain Zn bioavailability in diets containing 10 mg of Zn/kg from freeze-dried ground beef patties. This level of supplemental Zn was accomplished by adding 6.993% of freeze-dried ground beef to the basal diet at the expense of dextrose.

Previous research from our laboratory had indicated that tibia Zn is a linear function of supplemental Zn intake when Zn is added at levels < 45 mg/kg to a

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Soy concentrate, g</th>
<th>Egg white, g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dextrose</td>
<td>54.38</td>
<td>30.05</td>
</tr>
<tr>
<td>Cornstarch</td>
<td>—</td>
<td>30.36</td>
</tr>
<tr>
<td>Soy concentrate (65% CP)</td>
<td>34.47</td>
<td>—</td>
</tr>
<tr>
<td>Egg white (77.4% CP)</td>
<td>—</td>
<td>25.84</td>
</tr>
<tr>
<td>Corn oil</td>
<td>5.00</td>
<td>5.00</td>
</tr>
<tr>
<td>Solka flocc</td>
<td>—</td>
<td>3.00</td>
</tr>
<tr>
<td>Zn-free mineral mix</td>
<td>5.35</td>
<td>5.35</td>
</tr>
<tr>
<td>DL-methionine</td>
<td>.40</td>
<td>—</td>
</tr>
<tr>
<td>Choline chloride</td>
<td>.20</td>
<td>.20</td>
</tr>
<tr>
<td>Vitamin premix</td>
<td>.20</td>
<td>.20</td>
</tr>
<tr>
<td>DL-α-tocopheryl acetate (20 mg/kg)</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Ethoxyquin (125 mg/kg)</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

* aContained 22.4% CP, 14 mg of Zn/kg, and .92% phytate by analysis; calculated levels of Ca and available P were 1.1% and .55%, respectively.

bContained 20% CP and .32 mg of Zn/kg by analysis; calculated levels of Ca and available P were 1.1% and .55%, respectively.

Procon (Central Soya, Ft. Wayne, IN).

Egg albumin, spray-dried egg white (U.S. Biochemicals, Cleveland, OH).

Mineral mixture provided per kilogram of diet: CaCO₃, 3 g; Ca₃(PO₄)₂, 2 g; K,HPO₄, 9 g; NaCl, 8.8 g; MgSO₄·7H₂O, 3.5 g; MnSO₄·H₂O, .55 g; FeSO₄·7H₂O, .415 g; CuSO₄·5H₂O, .20 mg; ZnSO₄·7H₂O, 9 mg; Na₂MoO₄·2H₂O, 9 mg; KI, .40 mg; CoSO₄·7H₂O, 1 mg; and Na₂SeO₃, .215 mg.

Vitamin premix provided per kilogram of diet: thiamin-HCl, 20 mg; niacin, 50 mg; riboflavin, 10 mg; D-Capantothenate, 30 mg; vitamin B₁₂, .04 mg; pyridoxine-HCl, 6 mg; D-biotin, .5 mg; folic acid, 4 mg; menadione, 2 mg; ascorbic acid, 200 mg; cholecalciferol (200,000 IU/g), 600 IU; and retinyl acetate (950,000 IU/g), 5,200 IU.
s Soy-based diet containing 14 mg of Zn/kg (Wedekind and Baker, 1990; Wedekind et al., 1992). Moreover, in this response range and without resorting to a Zn-deficient pretest period, weight gain (and therefore basal Zn intake) is generally not affected by Zn supplementation during the course of a 14-d feeding period.

Experiment 2 was conducted to evaluate Zn bioavailability in a diet devoid of soy. Dietary levels of 0, 5, and 10 mg of Zn/kg from ZnSO₄ were added to the Zn-deficient egg-white diet (Table 1) at the expense of dextrose. The standard curve was compared with diets containing 10 mg of Zn/kg from freeze-dried ground beef (i.e., 6.993% of the diet as freeze-dried ground beef).

Statistical Analysis

Analysis of variance and regression analyses were conducted using the GLM procedure of SAS (1985). Total tibia Zn was regressed on supplemental Zn intake. Zinc bioavailability was determined relative to a ZnSO₄ standard by standard-curve methodology (Wedekind and Baker, 1990; Wedekind et al., 1992). The Y-variable for ground beef (tibia Zn content, micrograms) was substituted into the regression equation determined from the standard curve. Solving for X gave an estimate of the bioavailable Zn consumed. Dividing the bioavailable Zn by the actual Zn intake gave a relative bioavailability (percentage) estimate. Standard error values were obtained by determining a bioavailability estimate for each replicate. Treatment means were separated by single df comparisons.

Results

Experiment 1

Chicks gained more ($P < .05$) weight when fed diets containing 10 mg/kg of supplemental Zn from ground beef patties than when they were fed the other diets. This may have resulted because the freeze-dried ground beef provided more usable energy than the dextrose it replaced in the diet, or, alternately, because adding ground beef to the soy concentrate diet improved protein quality.

Total tibia Zn and tibia Zn concentration both responded linearly ($P < .01$) to supplemental Zn intake from ZnSO₄ (Table 2). Linear regression of total tibia Zn (Y) on supplemental Zn intake (X) yielded the equation $Y = 102.0 + 10.55X$ ($r = .87$). Standard-curve methodology was used to predict the relative Zn bioavailability of ground beef compared with the inorganic standard. This method indicated that ground beef patties had a relative Zn bioavailability of 111%, not different ($P > .05$) from 100%.

Experiment 2

Total tibia Zn and Zn concentration responded linearly ($P < .05$) to supplemental Zn added to the Zn-deficient egg-white diet (Table 3). The linear regression of total tibia Zn (Y) on supplemental Zn intake (X) was $Y = 20.71 + 21.65X$ ($r = .97$). Standard-curve methodology predicted a relative Zn bioavailability of 116% for ground beef, not different ($P > .05$) from 100%. In this experiment, as in Exp. 1, weight gain was greater ($P < .05$) in chicks fed the experimental diets containing added ground beef than in chicks fed diets with added ZnSO₄.

Table 2. Utilization of zinc by chicks fed a soy-protein-concentrate diet containing supplemental zinc from zinc sulfate or ground beef [Exp. 1]a

<table>
<thead>
<tr>
<th>Supplement</th>
<th>Suppl. Zn, mg/kg</th>
<th>Weight gain, g</th>
<th>Suppl. Zn intake, mg</th>
<th>Dry wt, g</th>
<th>Zn conc., μg/g</th>
<th>Total Zn, μg</th>
<th>RBV %</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>0</td>
<td>221</td>
<td>0</td>
<td>.99</td>
<td>91.8</td>
<td>91.0</td>
<td>—</td>
</tr>
<tr>
<td>ZnSO₄.H₂O</td>
<td>5</td>
<td>216</td>
<td>1.94</td>
<td>.97</td>
<td>141.6</td>
<td>137.3</td>
<td>—</td>
</tr>
<tr>
<td>ZnSO₄.H₂O</td>
<td>10</td>
<td>221</td>
<td>3.89</td>
<td>1.03</td>
<td>141.9</td>
<td>146.6</td>
<td>—</td>
</tr>
<tr>
<td>ZnSO₄.H₂O</td>
<td>15</td>
<td>228</td>
<td>5.81</td>
<td>.93</td>
<td>167.6</td>
<td>156.0</td>
<td>100</td>
</tr>
<tr>
<td>Ground beef</td>
<td>10</td>
<td>264</td>
<td>3.79</td>
<td>.98</td>
<td>149.5</td>
<td>146.3</td>
<td>111</td>
</tr>
<tr>
<td>Pooled SEM</td>
<td>—</td>
<td>7</td>
<td>.08</td>
<td>.02</td>
<td>6.5</td>
<td>3.3</td>
<td>12</td>
</tr>
</tbody>
</table>

aData represent means of four pens of four chicks during the period 8 to 22 d posthatching; average initial weight was 77 g.

bGround beef treatment different ($P < .05$) from the basal diet and all ZnSO₄ treatments.

cLinear ($P < .01$) response to ZnSO₄; at 10 mg/kg of supplemental Zn, ZnSO₄ not different from ($P > .05$) from ground beef.

dLinear regression of total tibia Zn (Y in micrograms) on supplemental Zn intake (X in milligrams) for Diets 1 to 4 was $Y = 102.0 + 10.55X$ ($r = .87$).

eThe lsd multiple comparison test indicated no difference ($P > .05$) between ZnSO₄ and ground beef relative for Zn bioavailability (RBV).

fGround beef patties were roasted, freeze-dried, and then finely ground before incorporation into the diet. The Zn concentration of the freeze-dried ground beef was 143 mg/kg.
Table 3. Utilization of zinc by chicks fed an egg-white-protein diet containing supplemental zinc from zinc sulfate or ground beef [Exp. 2]a

<table>
<thead>
<tr>
<th>Supplement</th>
<th>Suppl. Zn, mg/kg</th>
<th>Weight gain, g/b</th>
<th>Suppl. Zn intake, mg</th>
<th>Dry wt, g</th>
<th>Zn conc., µg/g</th>
<th>Total Zn, µg</th>
<th>RBVb</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>0</td>
<td>68</td>
<td>0</td>
<td>.50</td>
<td>36.6</td>
<td>18.3</td>
<td>—</td>
</tr>
<tr>
<td>ZnSO4 · H2O</td>
<td>5</td>
<td>158</td>
<td>1.64</td>
<td>.86</td>
<td>67.9</td>
<td>58.6</td>
<td>—</td>
</tr>
<tr>
<td>ZnSO4 · H2O</td>
<td>10</td>
<td>160</td>
<td>3.12</td>
<td>.89</td>
<td>96.7</td>
<td>86.1</td>
<td>100</td>
</tr>
<tr>
<td>Ground beef</td>
<td>10</td>
<td>191</td>
<td>3.11</td>
<td>.96</td>
<td>103.3</td>
<td>99.2</td>
<td>116</td>
</tr>
<tr>
<td>Pooled SEM</td>
<td>—</td>
<td>8</td>
<td>.05</td>
<td>.03</td>
<td>8.7</td>
<td>4.3</td>
<td>6</td>
</tr>
</tbody>
</table>

aData represent means of four pens of four chicks during the period 8 to 22 d posthatching; average initial weight was 70 g.

bZnSO4 at 5 and 10 mg/kg different (P < .01) from no supplemental Zn; the diet containing ground beef was greater (P < .05) than any of the diets not containing ground beef.

cLinear (P < .01) response to ZnSO4 at 10 mg/kg of supplemental Zn, ZnSO4 not different (P > .05) from ground beef.

dLinear regression of total tibia Zn (Y in micrograms) on supplemental Zn intake (X in milligrams) for diets 1 to 3 was Y = 20.71 + 21.65 (± 1.62) X (r = .97).

eThe lsd multiple comparison test indicated no difference (P > .05) between ZnSO4 and ground beef for relative Zn bioavailability (RBV).

fGround beef patties were roasted, freeze-dried, and then finely ground before incorporation into the diet. The Zn concentration of the freeze-dried ground beef was 143 mg/kg.

Discussion

Cooked ground beef contains approximately 65 mg of Zn/kg (Anonymous, 1990) or 143 mg of Zn/kg of freeze-dried product, as determined herein. Our results showed that the Zn in ground beef is as bioavailable as an inorganic Zn standard (ZnSO4). Shah and Belonje (1984), as well as Brown et al. (1985), also showed that the Zn in beef products is highly bioavailable to rats.

Pork products are generally lower in Zn than are beef products (Anonymous, 1990), but the Zn in pork loin has been shown to be more bioavailable than that in ZnSO4 (Hortin et al., 1991). In our studies with ground beef, Zn was 100% bioavailable relative to the Zn in ZnSO4, whether fed as a supplement to a diet containing phytate or to a diet devoid of phytate. In comparing our two experiments, however, Zn uptake by tibia was twice as great when increments of Zn were added to the phytate-free egg-white diet (21.65 µg/mg of supplemental Zn intake) as when Zn was added to the soy-concentrate diet (10.55 µg/mg of supplemental Zn intake). Whether this difference was due to the phytate contained in the soy diet (.92% phytate) or to the fact that chicks fed the soy diet were less Zn-deficient than those fed the egg-white diet cannot be stated with certainty. Chicks in Exp. 2 were fed the egg-white basal diet containing only .32 mg of Zn/kg diet during the 7-d pretest period, whereas chicks in Exp. 1 were fed a corn-soybean meal pretest diet (120 mg Zn/kg) during this period. As shown previously (Wedekind and Baker, 1990; Wedekind et al., 1992), feeding a Zn-deficient pretest diet depletes Zn stores. This explains, therefore, why depleted chicks in Exp. 2 showed a marked growth response to ZnSO4 (whereas those in Exp. 1 did not) during the 14-d experimental feeding period.

In a previous study from our laboratory (Wedekind et al., 1992) we had a direct comparison of bone Zn values (below the tibia Zn inflection point) for chicks pretested for 7 d on the Zn-deficient soy-concentrate diet (14 mg of Zn/kg) and then fed graded levels of ZnSO4 in either a soy-concentrate or a phytate-free crystalline amino-acid diet. Chicks fed the amino-acid diet accumulated Zn in bone at four times the rate of those fed the soy-concentrate diet that contained phytate. This suggests that the phytate in soy products reduces utilization of inorganic Zn supplements that are added to diets containing soy. Also, bone Zn uptake by chicks consuming corn-soybean meal diets is approximately the same as that which occurs in chicks fed soy-concentrate diets (Wedekind et al., 1992).

The Zn contained in meat products is utilized far better than that in plant-based food sources. Although the presence of phytate (in plant-based foods) may explain part of this difference, there may be other (meat) factors contributing to the superiority of meat-sources of Zn over vegetable sources. Our previous work with pork loin suggested that sulphydryl compounds (cysteine and glutathione) in meat products may contribute to the efficient use of Zn from these products (Hortin et al., 1991). Sulphydryl compounds are known to bind trace elements and increase their absorption efficiency (Layrisse et al., 1984; Wapnir and Stiel, 1986).

Implications

Ground beef is rich in Zn, and the Zn contained therein is as bioavailable as an inorganic Zn standard (i.e., ZnSO4). Zinc in cereal grains and oilseed products is much less bioavailable. Whether consumed
as part of a diet with or without phytate, Zn in meat products is highly available. As such, meat is an important contributor of bioavailable Zn to the human diet, and meat byproducts are probably important contributors of Zn to diets for animals.

**Literature Cited**


