In Vitro Binding Capacity of Various Fiber Sources for Magnesium, Zinc, and Copper

Ahmed Idouraine,† Bibi Z. Hassani,‡ Saffiatu S. Claye, and Charles W. Weber*

Department of Nutrition and Food Science, University of Arizona, Tucson, Arizona 85721

Sixteen fiber sources provided by different commercial suppliers were analyzed for moisture, acid detergent fiber (ADF), lignin, and endogenous minerals. They were further acid washed to strip them of their endogenous minerals and tested for their total binding capacity for magnesium (Mg), zinc (Zn), and copper (Cu). ADF content ranged from 14.5% for rice bran to 65.5% for pea fiber and lignin content from 0.5% for soy bran to 66% for pea fiber. Endogenous Mg varied from 250 μg/g for corn bran to 7995 μg/g for wheat bran. Zn levels were from 1.1 μg/g (oat "bleached" fiber) to 156 μg/g (wheat bran); those of Cu ranged from 1.0 μg/g (apple fiber) to 67.6 μg/g (peanut fiber). Acid washing was efficient in removing most endogenous minerals from fiber sources. The amounts of minerals bound varied significantly ($P < 0.05$) among fiber sources. Levels of Mg bound to acid-washed fibers ranged from 525 μg/g (oat hulls) to 4420 μg/g (pea fiber Centara), while those of Zn and Cu varied from 1861 μg/g (oat hulls) to 6990 μg/g (wheat bran) and from 639 μg/g (corn bran) to 7976 μg/g (barley fiber), respectively. Correlations and intercorrelations between the amount of minerals bound and protein, ADF, and lignin contents of acid-washed fiber sources were low because of the variation in the chemical composition and chemical structure of the fiber sources.

Keywords: *Dietary fiber; binding capacity; mineral binding; fibers and minerals*

INTRODUCTION

Recommendation for the increase of dietary fiber intake has raised questions about the possible negative effects on mineral bioavailability, particularly in population groups at high risk. Although there is evidence that high fiber intakes do influence mineral absorption, the subject is still controversial. To a certain extent, this could be explained by the composition of dietary fiber sources, the amount of fiber used in the diet, the length of the study, and other factors that may interfere with mineral utilization. Dietary fiber may affect mineral bioavailability by binding, diluting, and trapping minerals within dietary fiber particles and other physicochemical factors associated with the environment of food. The complexity of interactions that may take place between minerals and other components may be responsible for the mixed results reported in the literature.

In humans, Moak et al. (1987) found that addition of oat and wheat bran to the diet of adult males decreased copper, zinc, calcium, and magnesium absorption. Oat fiber had a tendency to cause more negative effects than wheat bran. A study on elderly patients, aged from 59 to 76 years, showed that a diet containing 30 g of wheat bran decreased significantly their calcium balance. Negative balances of calcium, magnesium, zinc, and phosphorus due to increased fecal excretion of each element were observed with increased fiber and phosphorus consumption as whole wheatmeal bread (Reinhold et al., 1976). In animal studies, Ward and Reichert (1986) reported that addition of 12% dietary fiber from canola cell wall, soybean cell wall, canola hull, soybean, and cellulose into rat diets produced lower apparent absorption of copper, iron, zinc, magnesium, calcium, and phosphorus. They attributed this reduction to the shorter intestinal transit time, greater fecal bulk, chelation of minerals, and tendency for fiber to affect the passive or active transport of minerals. Donangelo and Eggum (1986) compared the effects of wheat bran and barley husk on zinc, calcium, and phosphorus in 5 and 9 week old rats. Both fiber sources affected zinc and calcium absorption in the young animals but to different extents. In old animals zinc absorption did not change significantly.

Other studies, however, reported no effects of dietary fiber on mineral absorption. Shah et al. (1990) fed rats for 7 weeks with diets containing cellulose, oat bran, hard red spring wheat bran, soft white wheat bran, corn bran, and rodent lab chow at 4% and 14% total dietary fiber. They found that the fractional absorption of calcium, phosphorus, and magnesium by the young or adult rats was not significantly different. The fiber sources did not appreciably affect mineral levels in soft tissues and bones. Bagheri and Gueguen (1981) found that addition of wheat bran to rat diets had no adverse effects on calcium, magnesium, phosphorus, and zinc absorption.

In vitro studies indicate that the binding of minerals might be affected by the source of fibers, pH, and other physicochemical properties of dietary fiber. Persson et al. (1987) studied the ability of soluble fractions of wheat bran and whole grain wheat bread dough and cellulose to bind copper, zinc, and cadmium. Soluble fibers interacted strongly with metal ions, whereas the binding by cellulose was negligible. Fernandez and Phillips (1982) showed, however, that cellulose and pectin had little binding capacity on iron. Leigh and Miller (1983) showed that solubility and characteristics of iron in the diets are greatly affected by the nature of dietary ligands present in the meal and pH. Thompson and Weber (1979) studied the binding of several minerals by various fiber sources. They found that both fiber

* Author to whom correspondence should be addressed.

† Present address: Harrington Arthritis Research Center, 1800 Van Buren St., Phoenix, AZ 85006.

‡ Present address: P.O. Box 1526, Tempe, AZ 85281.

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source and pH had significant effects on mineral binding. Similar observations were reported by Camire and Clydesdale (1981) and Platt and Clydesdale (1987). Phytic acid and protein levels in dietary fibers are other factors that have been implicated in the binding of minerals and seen as a source of reduction in mineral bioavailability (Erdman, 1981; Champagne, 1988; Zhou et al., 1992).

The present literature review showed clearly that the effects of dietary fibers on mineral bioavailability are still controversial. Whereas some authors found no interactions between minerals and dietary fiber, others showed strong interaction. Since results obtained with one dietary fiber source do not necessarily apply to others because of differences in fiber levels, fiber composition, phytate content, methods used, and other factors that may interfere with mineral utilization, the study of the effects of various sources of fiber on mineral absorption is still therefore needed.

The purpose of this study is to investigate the *in vitro* binding capacity of 16 fiber sources for magnesium, zinc, and copper at pH 6.8, which represents the physiological pH at which most minerals are absorbed, and to test if there is any correlation between protein, acid detergent fiber, and lignin contents of these fiber sources and minerals bound.

MATERIALS AND METHODS

Fiber Sources. The 16 fiber samples were provided by commercial suppliers as follows: (1) apple fiber (Canadian Harvest, ON, Canada), (2) barley fiber (Canadian Harvest), (3) cane fiber (Canadian Fibre Foods Inc., BC, Canada), (4) cellulose (ICN Pharmaceuticals Inc., Staten Island, NY), (5) corn bran (Canadian Harvest), (6) oat hulls (National Oat Co., Cedar Rapids, IA), (7) oat fiber, bleached (Canadian Harvest), (8) orange fiber (D. D. Williamson & Co., Modesto, CA), (9) pea fiber Centara (Mid America Food Sales Ltd., Northbrook, IL), (10) pea fiber Dupro (Dupro Division, Golden Valley, MN), (11) peanut fiber (Canadian Harvest), (12) rice bran fiber (California Natural Products, Lathrop, CA), (13) soybean bran Nutrisoy (Archer Daniels Midland Co., Decatur, IL), (14) sugar beet fiber (Amalgamated Sugar Co., Twin Falls, ID), (15) tomato fiber (Canadian Harvest), and (16) certified hard red wheat bran (AACC, St. Paul, MN).

Analysis of the Various Fiber Sources. The 16 fiber sources were analyzed for moisture, acid detergent fiber (ADF), and lignin, in duplicates. Moisture content was calculated by subtracting the lyophilized weight from the original weight. ADF and lignin were determined according to the Van Soest (1963) method.

Mineral Binding and Analysis of the Fiber Sources. Defatted samples were shaken overnight in a 1% HCl solution (1:20 w/v) to remove endogenous minerals and then bound by mixing a portion of each fiber with separate mineral solutions (Weber et al., 1993). Duplicate 0.5 g samples of defatted (endogenous mineral), acid-washed, mineral-bound, and re-acid-washed samples were wet ashed as described by the AOAC Method 968.08 (AOAC, 1990) and then quantitatively transferred and made up to a suitable volume for analysis by atomic absorption spectrophotometry (Hitachi Model 180-70). The standard solutions were prepared daily from certified atomic absorption standards (Fisher Scientific, Fair Lawn, NJ). Standard curves were determined after every 10 samples. Precision was determined within runs (<5%) and between runs (<10%). Blanks were run for all samples to determine possible contamination. Magnesium samples were masked with a 1% lanthanum concentration to eliminate interferences with other minerals. Zinc and copper were diluted to the appropriate concentration from acid-digested mixtures and analyzed. All analyses were run in duplicate.

Table 1. Moisture, Acid Detergent Fiber (ADF), and Lignin Contents of the 16 Defatted Fiber Sources

fiber source	moisture,[a,b] %	ADF,[b] %	lignin,[a] %
apple fiber	5.96 ± 0.02[e]	57.23 ± 0.58[d,e]	15.03 ± 0.33[h]
barley fiber	4.96 ± 0.20[g,h]	24.76 ± 0.24[h]	4.38 ± 0.11[j,k]
cane fiber	3.85 ± 0.04[i,j]	40.10 ± 0.17[g]	32.52 ± 1.82[d]
cellulose	4.47 ± 0.06[h,i]	91.83 ± 0.54[a]	90.93 ± 1.11[a]
corn bran	5.74 ± 0.08[e,f]	20.59 ± 0.03[i]	20.00 ± 0.17[g]
oat hull	6.94 ± 0.04[c,d]	41.50 ± 0.05[g]	6.57 ± 0.03[i,j]
oat fiber, bleached	3.75 ± 0.19[j]	58.01 ± 0.28[d]	51.99 ± 0.23[c]
orange fiber	3.70 ± 0.02[j]	24.51 ± 1.73[h]	23.10 ± 1.29[f]
pea fiber Centara	7.56 ± 0.12[b,c]	64.98 ± 0.35[c]	63.87 ± 1.55[b]
pea fiber Dupro	5.25 ± 0.34[f,g]	67.57 ± 0.28[b]	65.96 ± 0.06[b]
peanut fiber	7.27 ± 0.23[b,c,d]	55.74 ± 1.99[e]	25.55 ± 3.55[e]
rice bran	8.46 ± 0.14[a]	14.51 ± 0.11[j]	8.49 ± 0.01[i]
soy bran	7.68 ± 0.01[b]	45.82 ± 0.42[f]	0.54 ± 0.05[l]
sugar beet pulp	6.82 ± 1.15[d]	25.33 ± 0.91[h]	0.78 ± 0.10[l]
tomato fiber	5.96 ± 0.26[e]	46.56 ± 0.11[f]	23.58 ± 0.11[e,f]
wheat bran AACC hard red wheat	7.81 ± 0.03[a,b]	15.14 ± 0.23[j]	3.93 ± 0.07[k]

[a] Determined in duplicate fat-free dry samples (mean ± SD). Different letters (a–l) within column are significantly different ($P < 0.05$).

Statistical Analysis. Data, expressed as a mean ± SD, were analyzed by analysis of variance (ANOVA) and *t*-test (Steel and Torrie, 1960), differences being significant when $P < 0.05$.

RESULTS AND DISCUSSION

Chemical Composition of the 16 Fiber Sources. Moisture, acid detergent fiber (ADF), and lignin contents of the various fiber sources are presented in Table 1. ADF values varied significantly ($P < 0.05$) among the fiber sources and ranged from 14.5% for rice bran to 67.6% (cellulose not included) for pea fiber Dupro. Five fiber sources had an ADF content over 50%, eight others a value between 20% and 40%, and two a value of less than 20%. There are few data in the literature reporting ADF values for different fiber sources. Our values are generally in the range of those cited by some authors (Thompson and Weber, 1979; Dintzis et al., 1979; Dreher, 1987). Lignin content ranged from 0.5% for soy bran to 66.0% (cellulose not included) for pea fiber Dupro. Lignin values varied significantly among the fiber sources, the lowest being those of soy bran, sugar beet fiber, and barley fiber (less than 5% lignin) and the highest pea fibers Dupro and Centara, and oat fiber bleached (over 50% lignin). Several authors have reported lignin values for cereal products, legumes, and fresh vegetables and fruits (Ross et al., 1985; Robertson, 1993), but only a limited number of studies dealt with fiber or bran sources (Dintzis et al., 1979; Anderson and Clydesdale, 1980).

Magnesium Content and Total Binding Capacity of the 16 Fiber Sources. Endogenous magnesium (Mg) of the different fiber sources varied significantly ($P < 0.05$) and ranged from 250 μg/g sample (cellulose excluded) for corn bran to 7995 μg/g for wheat bran (Table 2). Limited data have been reported in the literature on the endogenous Mg of fiber sources. Our values agree with those cited by Young et al. (1982) for oat fiber, by Platt and Clydesdale (1986) for wheat bran, and by Luh et al. (1991) for rice bran. Acid washing stripped most of the Mg from fiber sources (94.5–99.9% removal). The concentration of Mg in the acid-washed fibers ranged from 2 μg/g (cellulose excluded) for apple fiber to 106 μg/g for pea fiber Dupro. The binding capacity of the fiber sources for Mg was high and varied significantly among fiber sources. Oat hulls and cane fiber showed the lowest binding capacity (cellulose not

Table 2. Magnesium Content and Binding Capacity of the 16 Fiber Sources[a]

fiber source	magnesium content, μg/g			
	endogenous	acid-washed	total bound	re-acid-washed
apple fiber	$566 \pm 89^{j,x}$	$2 \pm 0^{j,y}$	1016 ± 163^{i}	$6 \pm 0.80^{i,j,y}$
barley fiber	$2010 \pm 18^{g,x}$	$50 \pm 4^{d,y}$	1427 ± 85^{h}	$17 \pm 0.90^{g,y}$
cane fiber	$492 \pm 6^{j,k,x}$	$11.6 \pm 1.7^{h,y}$	671 ± 2^{j}	$3 \pm 0.61^{j,k,y}$
cellulose	$37 \pm 0.4^{m,x}$	$1.2 \pm 0.3^{j,z}$	312 ± 1^{k}	$3 \pm 0.04^{j,k,y}$
corn bran	$250 \pm 0.7^{l,x}$	$2.4 \pm 0.4^{j,z}$	1944 ± 5^{fg}	$11 \pm 0.10^{h,y}$
oat hulls	$820 \pm 19^{i,x}$	$8.0 \pm 5.0^{i,y}$	$525 \pm 40^{j,k}$	$2 \pm 0.03^{k,y}$
oat fiber, bleached	$483 \pm 4^{k,x}$	$3.2 \pm 0.1^{j,y}$	1786 ± 37^{g}	$6 \pm 0.02^{i,j,y}$
orange fiber	$879 \pm 3^{i,x}$	$73.0 \pm 2^{c,y}$	3451 ± 146^{c}	$47 \pm 0.44^{b,z}$
pea fiber Centara	$3090 \pm 14^{d,x}$	$93.0 \pm 4^{b,y}$	4420 ± 27^{a}	$42 \pm 20^{c,z}$
pea fiber Dupro	$1942 \pm 52^{g,x}$	$106.0 \pm 3^{a,y}$	4080 ± 56^{b}	$38 \pm 6.90^{d,y}$
peanut fiber	$2324 \pm 25^{f,x}$	$19 \pm 9^{g,y}$	4129 ± 15^{b}	$30 \pm 1.50^{e,y}$
rice bran	$3736 \pm 159^{b,x}$	$3 \pm 1^{j,y}$	$1946 \pm 53^{f,g}$	$6 \pm 0.35^{i,y}$
soy bran	$2554 \pm 38^{e,x}$	$13 \pm 3^{h,y}$	3133 ± 300^{d}	$11 \pm 0.06^{h,y}$
sugar beet fiber	$1530 \pm 27^{h,x}$	$40 \pm 7^{e,z}$	3474 ± 50^{c}	$150 \pm 5^{a,y}$
tomato fiber	$3327 \pm 38^{c,x}$	$19 \pm 4^{g,y}$	2091 ± 30^{f}	$25 \pm 0.80^{f,y}$
wheat bran AACC hard red wheat	$7995 \pm 73^{a,x}$	$35 \pm 6^{f,y}$	2439 ± 58^{e}	$37 \pm 0.90^{d,y}$

[a] Determined on duplicate fat-free dry samples (mean ± SD). Mean values with the same superscript (a–n) within columns are not significantly different. Mean values for endogenous and acid- and re-acid-washed fibers with different letters (x–z) within row are significantly different ($P < 0.05$).

Table 3. Zinc Content and Binding Capacity of the 16 Fiber Sources[a]

fiber source	zinc content, μg/g			
	endogenous	acid-washed	total bound	re-acid-washed
apple fiber	$16.8 \pm 6.00^{g,h,y}$	$0.0 \pm 0.00^{e,z}$	2020 ± 163^{j}	$87 \pm 2.20^{d,e,x}$
barley fiber	$52.0 \pm 3.40^{d,e,x}$	$1.8 \pm 0.30^{c,z}$	6105 ± 71^{d}	$10 \pm 0.80^{g,h,i,y}$
cane fiber	$20.8 \pm 1.08^{g,x}$	$0.0 \pm 0.00^{e,z}$	1948 ± 30^{j}	$4 \pm 0.24^{i,y}$
cellulose	$0.0 \pm 0.0^{k,y}$	$0.0 \pm 0.00^{e,y}$	821 ± 42^{k}	$1 \pm 0.01^{i,x}$
corn bran	$8.6 \pm 0.11^{j,y}$	$0.0 \pm 0.00^{e,z}$	5033 ± 14^{f}	$20 \pm 0.30^{g,x}$
oat hulls	$10.8 \pm 3.10^{i,j,y}$	$0.0 \pm 0.00^{e,z}$	1861 ± 155^{j}	$19 \pm 0.70^{g,h,x}$
oat fiber, bleached	$1.1 \pm 0.50^{k,y}$	$0.0 \pm 0.00^{e,y}$	3681 ± 88^{h}	$8 \pm 0.03^{h,i,x}$
orange fiber	$9.7 \pm 0.04^{j,y}$	$0.7 \pm 0.07^{d,z}$	$5859 \pm 25^{d,e}$	$154 \pm 18.00^{b,x}$
pea fiber Centara	$16.1 \pm 0.52^{g,h,i,y}$	$0.9 \pm 0.38^{d,z}$	$6451 \pm 91^{b,c}$	$95 \pm 4.00^{d,x}$
pea fiber Dupro	$47.6 \pm 2.11^{e,y}$	$2.3 \pm 0.16^{b,c,z}$	5673 ± 42^{e}	$94 \pm 7.00^{d,x}$
peanut fiber	$53.4 \pm 3.20^{d,y}$	$2.9 \pm 0.39^{a,b,z}$	6399 ± 390^{c}	$140 \pm 4.40^{c,x}$
rice bran	$93.5 \pm 1.94^{b,x}$	$2.0 \pm 0.19^{c,z}$	2347 ± 4^{i}	$6 \pm 0.20^{i,y}$
soy bran	$61.7 \pm 0.00^{c,y}$	$0.9 \pm 0.18^{d,z}$	$6713 \pm 221^{a,b}$	$77 \pm 0.50^{e,x}$
sugar beet fiber	$13.6 \pm 1.17^{h,i,j,y}$	$0.3 \pm 0.04^{d,e,z}$	5114 ± 100^{f}	$151 \pm 6.00^{b,c,x}$
tomato fiber	$41.4 \pm 1.30^{f,y}$	$2.8 \pm 0.21^{a,b,z}$	4108 ± 64^{g}	$63 \pm 0.80^{f,x}$
wheat bran AACC hard red wheat	$155.7 \pm 5.90^{a,y}$	$3.2 \pm 1.46^{a,z}$	6990 ± 9^{a}	$212 \pm 6.00^{b,c,x}$

[a] Determined in duplicate fat-free dry samples (mean ± SD). Mean values with the same superscript (a–k) within columns are not significantly different. Mean values for endogenous and acid- and re-acid-washed fibers with different letters (x–z) within row are significantly different ($P < 0.05$)

included), while pea and peanut fibers the highest. This might be related to their difference in chemical composition and particle sizes. Fiber sources from legumes (pea fiber Centara and Dupro, peanut fiber, and soy bran) seem to bind more Mg than those of cereals (barley fiber, corn bran, oat hulls and bleached oat fiber, and wheat bran). This binding does not appear to be directly related either to the protein content or to the phytic acid levels of these fiber sources (Weber et al., 1993). This might suggest that other components are involved in the binding or that legume fibers might have more specific binding sites for Mg than those of cereal fibers. Four fiber sources (wheat bran, tomato fiber, rice bran, and oat hulls) were not able to rebind Mg to its original level. The high binding capacity of sugar beet fiber could be related to the high water holding capacity of this fiber (Weber et al., 1993). Re-acid-washing removed significant amounts of Mg from bound fiber sources. Retained values ranged from 2 μg/g for oat hulls to 150 μg/g for sugar beet fiber.

Zinc Contents of the Raw and Treated Fiber Sources. Zinc (Zn) contents of the raw, acid-washed, and bound fiber sources are listed in Table 3. Endogenous Zn varied significantly ($P < 0.05$) among fiber sources and ranged from 1.1 μg/g (cellulose not included) for bleached oat fiber to 155.7 μg/g for wheat bran. These values did not always agree with those cited in the literature (Thompson and Weber, 1979; Platt and Clydesdale, 1986; Luh et al., 1991). Differences in fiber sources and methods used might explain these variations. Acid washing stripped most of the Zn from the fiber sources. The level of Zn left after acid washing varied from 0.0 to 3.2 μg/g sample (92.8–100% removal). Six fiber sources had 100% of their Zn completely removed, suggesting that Zn might be entirely available at acid pH. Thompson and Weber (1979) and Lyon (1984) showed that more Zn was released at low than at high pH. The binding capacity of fiber sources for Zn varied significantly ($P < 0.05$) and ranged from 1861 μg/g (cellulose not included) for oat hulls to 6990 μg/g for wheat bran. With the exception of apple fiber, which showed lower Zn binding, our values were higher than those cited by Casterline and Ku (1993) but agree with those reported by Platt and Clydesdale (1986) for wheat bran. The binding capacity of these fiber sources does not appear to be directly related either to their protein and phytic acid contents or to their water holding capacity (Weber et al., 1993). Combined effects of these

Table 4. Copper Content and Total Binding Capacity of the 16 Fiber Sources[a]

fiber source	copper content, μg/g			
	endogenous	acid-washed	total bound	re-acid-washed
apple fiber	$1.0 \pm 0.00^{f,y}$	$0.8 \pm 0.50^{c,y}$	5112 ± 387^{d}	$73 \pm 0.90^{g,h,x}$
barley fiber	$2.9 \pm 0.50^{f,y}$	$1.9 \pm 0.30^{c,y}$	7976 ± 232^{a}	$47 \pm 0.50^{i,x}$
cane fiber	$1.2 \pm 0.18^{f,y}$	$0.3 \pm 0.15^{c,y}$	1327 ± 98^{h}	$26 \pm 0.57^{j,x}$
cellulose	$0.6 \pm 0.09^{f,y}$	$0.1 \pm 0.10^{c,z}$	$1026 \pm 4^{h,i}$	$5 \pm 0.08^{k,x}$
corn bran	$1.6 \pm 0.03^{f,y}$	$0.1 \pm 0.04^{c,y}$	639 ± 56^{i}	$58 \pm 0.90^{h,i,x}$
oat hulls	$1.2 \pm 0.00^{f,y}$	$1.5 \pm 1.30^{c,y}$	3786 ± 213^{e}	$12 \pm 0.40^{j,k,x}$
oat fiber, bleached	$1.3 \pm 0.62^{f,y}$	$0.3 \pm 0.08^{c,y}$	1123 ± 101^{h}	$48 \pm 1.41^{i,x}$
orange fiber	$2.7 \pm 0.11^{f,y}$	$1.4 \pm 1.15^{c,y}$	2000 ± 46^{g}	$206 \pm 1.45^{d,x}$
pea fiber Centara	$1.4 \pm 0.01^{f,y}$	$0.7 \pm 0.08^{c,y}$	3167 ± 493^{f}	$312 \pm 8.20^{b,x}$
pea fiber Dupro	$11.0 \pm 5.96^{c,y}$	$1.6 \pm 0.10^{c,y}$	2063 ± 308^{g}	$247 \pm 6.00^{c,x}$
peanut fiber	$67.4 \pm 3.70^{a,y}$	$9.8 \pm 3.80^{a,z}$	7116 ± 161^{b}	$141 \pm 4.50^{e,x}$
rice bran	$8.4 \pm 0.10^{d,y}$	$5.6 \pm 0.04^{b,z}$	1297 ± 86^{h}	$82 \pm 1.14^{g,x}$
soy bran	$7.0 \pm 1.30^{d,e,y}$	$1.6 \pm 0.70^{c,z}$	$6915 \pm 145^{b,c}$	$105 \pm 0.70^{f,x}$
sugar beet fiber	$5.0 \pm 0.20^{e,f,y}$	$0.8 \pm 0.03^{c,y}$	5475 ± 43^{d}	$702 \pm 35^{a,x}$
tomato fiber	$2.0 \pm 0.20^{f,y}$	$1.0 \pm 0.20^{c,y}$	6680 ± 13^{c}	$60 \pm 3.00^{h,i,x}$
wheat bran AACC hard red wheat	$16.0 \pm 0.60^{b,y}$	$6.0 \pm 5.00^{b,z}$	7134 ± 12^{b}	$49 \pm 0.90^{i,x}$

[a] Determined on duplicate fat-free dry samples (mean ± SD). Mean values with the same superscript (a–k) within columns are not significantly different. Mean values for endogenous and acid- and re-acid-washed fibers with different letters (x–z) within row are significantly different ($P < 0.05$).

Table 5. Linear Regression (y_1, y_2, y_3), Pearson's Coefficient Correlation (r_1, r_2, r_3), and Multiple Correlations ($r_{1,2,3}$) of Protein, Acid Detergent Fiber (ADF), and Lignin vs Total Binding Capacity of Zn, Mg, and Cu

dependent variables vs independent variables[a]	Zn		Mg		Cu	
protein (N × 6.25)[b]	$y_1 = 4.4 + 0.001x$	$(r_1 = 0.263)$	$y_1 = 4.6 + 0.002x$	$(r_1 = 0.247)$	$y_1 = 2.2 + 0.002x$	$(r_1 = 0.491)$
ADF	$y_2 = 54.6 - 0.002$	$(r_2 = 0.206)$	$y_2 = 44.4 - 0.001x$	$(r_2 = -0.028)$	$y_2 = 49.7 - 0.002x$	$(r_2 = -0.194)$
lignin	$y_3 = 39.7 - 0.003x$	$(r_3 = -0.187)$	$y_3 = 25.9 + 0.001x$	$(r_3 = 0.030)$	$y_3 = 25.9 + 0.006x$	$(r_3 = 0.557)$
		$(r_{1,2,3} = 0.228)$		$(r_{1,2,3} = 0.301)$		$(r_{1,2,3} = 0.789)$

[a] Dependent (Zn, Mg, and Cu) vs independent variables (protein content of acid washed fibers, ADF, and lignin). [b] Calculated from values reported in Weber et al. (1993).

components and other factors are probably responsible for these differences in binding. Re-acid-washing removed a large amount of Zn from fiber sources. Zn levels of re-acid-washed fibers were significantly higher than those of defatted and acid-washed samples. Some strong complexes between Zn and fiber sources might have been formed, leading to less removal of Zn when compared to acid-washed samples.

Copper Content of Raw and Treated Fiber Sources. Copper (Cu) contents of untreated and treated fiber sources are presented in Table 4. Endogenous Cu was low and varied from 1.0 μg/g (cellulose not included) for apple fiber to 67.4 μg/g for peanut fiber. Only wheat and rice brans had Cu value over 10 μg/sample. Limited data have been reported in the literature on endogenous Cu of fiber sources. Our values agree with those reported by Thompson and Weber (1979) and those found by Platt and Clydesdale (1986) for wheat bran. Acid washing removed most of the Cu from fiber sources. The Cu left in the fiber sources ranged from 0.1 μg/g for oat hulls and tomato fiber to 9.8 μg/g for peanut fiber. The total binding capacity of the 16 fiber sources for Cu varied significantly ($P < 0.05$) and ranged from 639 μg/g for corn bran to 7976 μg/g for barley fiber. Re-acid-washing removed a large portion of Cu bound to fiber sources but not to the level of that of acid-washed or endogenous samples. Formation of Cu complexes leading to lower solubility might be responsible for these higher values.

Correlations between Some Variables and Total Binding Capacity of the 16 Fiber Sources. Linear regression, Pearson's correlation coefficient, and multiple correlation coefficients of protein, acid detergent fiber, and lignin versus the total binding capacity of the 16 fiber sources for Zn, Mg, and Cu are reported in Table 5. Protein, ADF, and lignin had low correlations with Zn, Mg, and Cu. Overall, protein exhibited better correlation than ADF or lignin. There also appears to be some intercorrelation between the three variables and minerals bound, particularly with Cu. Although protein, phytic acid, and uronic acid contents are known to affect mineral binding, there must be other factors and/or more complex mechanisms involved in the binding of fibers for minerals.

Conclusion. Acid detergent fiber, lignin, and endogenous Mg, Zn, and Cu contents varied widely among the fiber sources studied. Endogenous Mg in fiber sources was higher than that of Zn and Cu. Overall, Zn and Cu bound more to fibers than Mg. Cellulose had low binding capacities for the three minerals. Mg and Zn appeared to bind preferentially to pea and peanut fibers, while Cu bound barley and peanut fiber and wheat bran. The amounts of Mg, Zn, and Cu bound to fiber sources do not appear to be strongly correlated to the protein, acid detergent fiber, or lignin contents. This is probably due to the variation in chemical composition and chemical structures of these fiber sources when considered as a whole. Other components or more complex mechanisms might also be involved. Further work is needed on the total binding of fiber sources for minerals not only to understand the mechanism involved but also to predict the degree of binding of a given fiber for a given mineral, which could be useful for consumers.

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