Effect of Diet Fiber Level on Bowel Function and Trace Mineral Balances of Human Subjects[1]

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ABSTRACT

A review of the literature dealing with effects of fiber on bowel function and trace mineral balances of human subjects was conducted. Fiber in the diet decreased bowel transit times of subjects with long transit times. Fiber increased number of stools, fecal weight, and fecal excretions of energy, nitrogen, and fat. In most studies, fiber did not affect the iron balance. However, fiber decreased zinc and copper balances in some studies. Some investigators reported high correlations of fecal fiber with fecal minerals. Significant positive correlations of fecal minerals with fecal weight and fecal fiber may indicate binding of minerals by fiber. In addition to levels of fiber intake, levels of trace mineral intakes, phytic acid, and other dietary components probably influenced the trace mineral balances in the studies reviewed. Length of time of the studies must also be considered. Further study of the factors affecting trace mineral balances is needed.

Research has suggested that fiber binds minerals in the digestive tract, possibly rendering them unavailable for absorption by the body. Absorption of minerals also might be decreased because of dilution from the extra water taken up by the fiber or because of faster transit through the intestines. Correlations between transit time, number of defecations, fecal weight, and other variables have not generally been computed for studies on the effects of fiber.

BOWEL FUNCTION

The literature on the effects of fiber intake on bowel function was reviewed previously (Kelsay 1978). Increased fiber intake generally increased the number of stools and sometimes decreased transit times. Fiber tended to shorten long transit times but did not affect short ones. Fiber in the diet generally increased stool weights and fecal excretion of energy, nitrogen, and fat. In one study conducted in our laboratory, mean transit time of 12 men decreased from 52 hr on a low fiber diet to 38 hr on a diet containing fruits and vegetables (Kelsay et al 1978). In a second study, in which we fed a low fiber diet and three diets containing increasing levels of fruits and vegetables, mean transit time on the low fiber diet was 30 hr and was not affected by increasing levels of fiber intake (Kelsay et al 1979b). The inclusion of fruits and vegetables in the diet increased fecal weight, number of defecations, and fecal excretions of energy, nitrogen, and fat in both studies.

IRON METABOLISM

Results of most human balance studies indicate that fiber does not affect iron balance (Table I). However, in one of the first studies, Widdowson and McCance (1942) found that iron balances of four women and four men were more positive when bread in their diets was white rather than brown, even though brown bread supplied 50% more iron than did white bread. Iron intakes were 12–22 mg/day on white bread and 18–31 mg/day on brown bread diets. The bread supplied 40–50% of the calories. Subjects consumed the white bread diet for 42–70 days and the brown bread diet for 42–91 days; seven-day balances were done throughout the study.

Walker et al (1948) reported that iron balance did not differ between diets with brown and white bread when iron intakes were 15–26 mg/day. Three subjects consumed the white bread diet for one to four weeks and the brown bread diet for three to five weeks; seven-day balances were done.

Cullumbine et al (1950) found that replacing polished rice with unpolished rice did not affect iron balance with iron intakes of 11–23 mg/day. Twelve subjects consumed the polished rice diet for two to three weeks and the unpolished rice diet for three weeks. Balances were done on the last seven days.

Sandstead et al (1978) reported that the addition of 26 g of soft white wheat bran or corn bran to a basal diet containing 11–20 mg of iron had no effect on iron balance. Seven male subjects consumed the basal diet and five consumed the diet with added bran for 28–30 days. Balances were determined on the last 12 days of each period.

We compared the effects of a low fiber diet containing 4 g of neutral detergent fiber (NDF) with a diet containing 24 g of NDF from fruits and vegetables. The NDF content was determined by the method of Goering and Van Soest (1970). Mean iron intakes were 21.8 and 26.4 mg/day on the low fiber diet and the diet containing fruits and vegetables, respectively. Twelve men consumed each diet for 26 days, and balances were done on the last seven days of each dietary period. Iron balance was not affected by the inclusion of fruits and vegetables in the diet (Kelsay et al 1979a).

High levels of iron intake may prevent adverse effects of fiber on iron balance. Haghshenass et al (1972) corrected iron-deficiency anemia due to poor availability of iron by giving iron supplements to people in Iran who were consuming large amounts of unleavened wholemeal wheat bread. Blood hemoglobin levels and packed red cell volume increased when the iron supplements were given. Apte and Venkatachalam (1962) found that an iron intake of 17–21 mg/day was needed to maintain positive iron balance with a cereal diet containing high phytate. Hussain and Patwardhan (1959) reported that iron balance could be established with about 22 mg of iron per day on a mixed vegetarian diet containing high phytate, although balances decreased on the higher phytate diet.

Although balance figures were not given, Reinhold et al (1975) reported increased fecal iron in two subjects fed 10 g of cellulose daily for 14 days.

Absorption of iron as measured by serum iron levels was less when wholemeal flour was eaten in place of white flour (Dobbs and Baird 1977, Elwood et al 1970, Vellar et al 1968) and when bran was added to rolls (Bjorn-Rasmussen 1974).

In two studies in which wheat fiber was given, serum iron levels fell (Jenkins et al 1975, Persson et al 1975) and mean corpuscular volume and mean corpuscular hemoglobin levels fell (Jenkins et al 1975). In another study, hemoglobin levels did not differ between groups of subjects consuming white and whole wheat bread (Heaton et al 1976).

These increased excretions and decreased absorptions of iron were previously attributed to the presence of phytate in the unrefined cereals (Apte and Venkatachalam 1962, Bjorn-Rasmussen 1974, Haghshenass et al 1972, Hussain and Patwardhan 1959, Jenkins et al 1975, Vellar et al 1968, Widdowson and McCance 1942). However, recent studies indicate that the fiber in the unrefined cereal may be responsible for the increased excretion of minerals (Ismail-Beigi et al 1977b, Reinhold et al 1976a). Totally dephytinized wholemeal bread and bran (Ismail-Beigi et al 1977a, Reinhold et al 1975, Reinhold et al 1976b) and

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residues of various plant foods (James et al 1978) bound minerals in vitro.

The absorption of nonheme iron from foods such as vegetables, grains, fruits, and eggs (Monsen et al 1978) was enhanced by ascorbic acid and animal tissues in the diet. These factors might also confound the evaluation of iron balance studies.

ZINC METABOLISM

Some, but not all, investigators reported evidence that fiber decreases zinc balance (Table II). Reinhold et al (1973b) studied three subjects on a diet containing 350 g of white bread for 16 days and 350 g of unleavened wholemeal bread for 32 days. In a subsequent study, the same investigators (Reinhold et al 1976a) fed 60% of the energy as white bread or as leavened wholemeal bread to two subjects for 20 days each. Balances were determined every four days during the first study and every two days during the second study. Zinc intake was 19 mg/day in the second study and was even higher in the first study. In both studies, zinc balances became negative when wholemeal bread was consumed.

When Ismail-Beigi (1977b) added 10 g of cellulose in apple compote to the low fiber diet containing white bread described by Reinhold et al (1976a), zinc balances became negative for the three subjects for ten two-day balance periods. Zinc intake was about 15 mg/day. When the cellulose in apple compote was added to a diet containing unleavened wholemeal bread, negative zinc balances of the two subjects became even more negative on zinc intakes of 13 mg/day.

Sandstead et al (1978) studied nine subjects on a basal diet and five subjects each on the same diet with 26 g of either soft white wheat bran or corn bran added. Zinc intakes were 10–15 mg/day, and balances were done during the last 12 days of 28–30 day periods. Soft white wheat bran appeared to decrease zinc balance in four of five subjects, but the decrease was not significant. Corn bran did not affect zinc balance.

In a study by Guthrie and Robinson (1978), four women added 14 g of wheat bran to self-selected diets for four weeks. Tests during week four revealed no overall changes attributable to the bran, but zinc balances of two of the four subjects decreased.

Drews et al (1979) added 14.2 g of either cellulose, hemicellulose, or pectin to a basal diet fed eight adolescent males for four days each. Hemicellulose significantly lowered the zinc balance.

Papakyrikos et al (1979) added 10 or 20 g of hemicellulose, cellulose, or wheat bran to a control diet consumed by seven women for seven days each. All fiber sources tended to increase fecal zinc loss.

Kies et al (1979) supplemented the constant diet of 12 men with 4.2, 14.2, and 24.2 g of hemicellulose for 14-day periods. Zinc intake was held constant at 11.3 mg/day. Increasing the hemicellulose intake decreased the zinc balance, which was negative on the highest level of hemicellulose intake. Balances for days 1–7 were not significantly different from those for days 8–14.

In a study conducted in our laboratories on 12 men, zinc intake was 13.2 mg/day on a low fiber diet containing 4 g of NDF and 12.6 mg on a higher fiber diet containing 24 g of NDF from fruits and vegetables. During the last seven days of a 26-day period, the mean zinc balance on the higher fiber diet was negative and was significantly lower than that on the low fiber diet (Kelsay et al 1979c). In a second study, we fed a low fiber diet containing 2 g of NDF and three diets containing 10, 18, or 25 g of NDF from fruits and vegetables (Kelsay et al 1979b). Fiber content of the diets in this study was determined using the American Association of Cereal Chemists' modification of the NDF method (1978), which resulted in lower values than those obtained with the original method. Mean zinc intakes on the four diets ranged from 11.8 to 12.4 mg/day. Zinc balance was significantly less on 25 g of NDF intake than on 2 or 10 g of NDF.

In the studies by Reinhold et al (1973b, 1976a), higher levels of zinc intake did not prevent the negative balances. The lack of effect of fiber on zinc balance reported by other investigators may be the result of lower levels of fiber intake than were fed in the studies by Reinhold and coworkers. In one study (Reinhold et al 1976a), the acid detergent fiber (ADF) intake of two subjects was 22 g/day on the low fiber diet and 30 and 34 g/day on the high fiber diet. The

TABLE I
Effect of Fiber on Iron Balance

Investigators	Fiber Source	Iron Balance
Widdowson and McCance (1942)	Brown bread (40–50% of calories) for 42–91 days	Decreased by brown bread, but mean balances positive
Walker et al (1948)	Brown bread (1 lb per day) for three to five weeks	Not affected by brown bread
Cullumbine et al (1950)	Unpolished rice (27 oz per day, cooked) for three weeks	Not affected by unpolished rice
Sandstead et al (1978)	Soft white wheat bran (26 g) or corn bran (26 g) for 28–30 days	Not affected by either bran
Kelsay et al (1979a)	Fruits and vegetables with 24 g of neutral detergent fibers for 26 days	Not affected by fruits and vegetables

TABLE II
Effect of Fiber on Zinc Balance

Investigators	Fiber Source	Zinc Balance
Reinhold et al (1973b)	Unleavened wholemeal bread (350 g/day) for 32 days	Became negative with wholemeal bread
Reinhold et al (1976a)	Leavened wholemeal bread (60% of calories) for 20 days	Became negative with wholemeal bread
Ismail-Beigi et al (1977b)	Cellulose (10 g) in apple compote for 20 days	Negative with addition of cellulose
Sandstead et al (1978)	Soft white wheat bran (26 g) or corn bran (26 g) for 28–30 days	Not significantly affected by bran
Guthrie and Robinson (1978)	Wheat bran (14 g) for four weeks	Not significantly affected by bran
Drews et al (1979)	Cellulose, hemicellulose, or pectin (14.2 g) for four days	Significantly lowered by hemicellulose
Papakyrikos et al (1979)	Cellulose, hemicellulose, or wheat bran (10 or 20 g) for seven days	Tendency of all sources to increase fecal zinc loss
Kies et al (1979)	Hemicellulose (4.2, 14.2, or 24.2 g) for 14 days	Decreased as fiber intake increased; negative with highest level of fiber
Kelsay et al (1979c)	Fruits and vegetables; 24 g of NDF[a] for 26 days	Negative with fruits and vegetables
Kelsay et al (1979b)	Fruits and vegetables; 10, 18, or 25 g of NDF for 21 days	Significantly lower on 25 g of NDF than on low fiber diet or on 10 g of NDF

[a]NDF = Neutral detergent fibers.

level of fiber intake of the subjects studied by Ismail-Beigi et al (1977b) was 18–19 g of ADF per day on the low fiber diet, and 33–37 g of ADF per day on the higher level of fiber intake. The ADF method does not measure hemicellulose, so the intakes of total dietary fiber were probably considerably higher than the values reported.

A zinc-deficient population in Iran, where zinc absorption was poor because of large intakes of wholemeal wheat bread, responded to zinc supplementation (Halsted et al 1972). Villagers in Iran, who had eaten wholemeal bread all of their lives, retained abnormally high proportions of calcium, zinc, and phosphorus when these minerals were given in available forms (Reinhold et al 1973a). Two subjects fed a diet containing unleavened whole wheat bread had negative balances of zinc, calcium, magnesium, and phosphorus after 16 days (Reinhold et al 1976b) but had positive balances of zinc and phophorus after 45 days on the same diet.

Harland et al (1979) reported on 28 men and women whose diets were supplemented for 15 weeks with wheat flakes or wheat bran. Zinc intake remained constant. Plasma zinc levels fell 10 μg/dl in both supplemented groups. Ismail-Beigi et al (1977b) also found that plasma zinc decreased when cellulose in apple compote was added to the diet.

COPPER METABOLISM

The effect of fiber on copper metabolism has not been widely studied (Table III). Sandstead et al (1978) reported that the addition of 26 g of soft white wheat bran to the diet apparently improved copper balance, possibly because the bran increased copper intake from 1.11 mg/day to 1.32 mg/day. The addition of 26 g of corn bran did not affect copper balance. Drews et al (1979) found that 14.2 g of hemicellulose, but not of cellulose or pectin, lowered copper balance. Plant et al (1979) reported that cellulose, but not hemicellulose or pectin, significantly lowered copper balance when copper intakes were 4.5 or 6.5 mg/day.

In our first study, copper intakes of 12 men studied for 26 days were 1.8 g/day on the low fiber diet and 1.6 g/day on the higher fiber diet containing fruits and vegetables. Mean copper balance was negative on the higher fiber diet and was significantly less than that on the low fiber diet (Kelsay et al 1979c). In a second study (Kelsay et al 1979b), we fed a low fiber diet and three diets with increasing amounts of fruits and vegetables to 12 men for 21 days each. Copper intakes ranged from 2.3–3.0 mg/day on the four diets. Copper balances did not differ significantly among diets.

TABLE III
Effect of Fiber on Copper Balance

Investigators	Fiber Source	Copper Balance
Sandstead et al (1978)	Soft white wheat bran (26 g) or corn bran (26 g) for 28–30 days	Apparently improved by wheat bran; no effect from corn bran
Plant et al (1979)	Cellulose, hemicellulose, or pectin	Tendency of fiber to cause increased fecal copper excretion and poorer copper balance, but significant only with cellulose
Drews et al (1979)	Cellulose, hemicellulose, or pectin (14.2 g) for four days	Significantly lowered by hemicellulose
Kelsay et al (1979c)	Fruits and vegetables; 24 g of neutral detergent fibers for 26 days	Negative with fruits and vegetables
Kelsay et al (1979b)	Fruits and vegetables; 10, 18, or 25 g of neutral detergent fibers for 21 days	Not affected by increasing levels of fiber

In our first study, zinc, but not iron or copper, was significantly correlated with fiber excretion and fiber intake. Fecal iron, zinc, and copper were significantly correlated with fecal weight and with fecal energy, nitrogen, fat, calcium, magnesium, phosphorus, and with each other. Fecal iron, zinc, and copper were not significantly correlated with bowel transit time or number of stools.

In our second study, zinc and copper excretions in feces were significantly correlated with fecal weight, calories, fat, nitrogen, calcium, magnesium, and with each other. Zinc and copper in feces were not significantly correlated with bowel transit time or number of stools. Fiber analyses have not been completed on these samples, so correlations with fiber are not available. Reinhold et al (1976b) and Ismail-Beigi et al (1977b) reported high correlations of fecal fiber with fecal minerals. These high correlations could indicate binding of minerals to fiber. However, in our two studies, some of these high correlations appeared to result merely from the fact that subjects consuming higher caloric diets also consumed more nutrients and more fiber and thus excreted more of everything in the feces.

Further studies are being conducted in our laboratories in an attempt to ascertain why dietary fiber resulted in negative balances of some minerals in one study and only decreased the balance of zinc in the other study. Possibly mineral balances in the first study were affected by the oxalic acid content of the spinach given with the higher fiber diet. Phytic acid was not a complicating factor in our two studies, as our diets were virtually free of phytic acid.

CONCLUSIONS

An increase of fiber in the diet increases stool weights and number of defecations and decreases bowel transit time in subjects with long transit times. Thus, the inclusion of fiber in the diet is very important in regulating bowel function and in the prevention of constipation. Fiber also increases fecal excretions and decreases apparent digestibilities of energy, fat, and nitrogen.

Even after a number of studies, the effect of fiber on mineral balances of human subjects is not clear, undoubtedly because so many factors can influence mineral balance. The effects of phytic acid, or phytic acid plus fiber, have not been clearly delineated. The effects of other complexing agents, such as oxalic acid consumed with fiber, have not been investigated. The timespan of a study must also be considered. We do not know whether subjects whose mineral balances are negative or decreased when they eat diets containing substances that may render minerals unavailable could adjust to lower bioavailability if given an extended time. Higher levels of mineral intake should logically compensate for negative balances resulting from unavailability of minerals due to certain dietary factors, but even this aspect requires further study. If fiber does bind minerals and make them unavailable to the body, the levels of fiber and mineral intakes would be very important. Significant positive correlations of fecal minerals and other nutrients with fecal weight and fecal fiber might indicate that fiber does bind dietary components.

LITERATURE CITED

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1976. Approved Methods of the AACC. Method 32-20, approved October 1977. The Association: St. Paul, MN.

APTE, S. V., and VENKATACHALAM, P. S. 1962. Iron absorption in human volunteers using high phytate cereal diet. Ind. J. Med. Res. 50:516.

BJORN-RASMUSSEN, E. 1974. Iron absorption from wheat bread. Influence of various amounts of bran. Nutr. Metabol. 16:101.

CULLUMBINE, H., BASNAYAKE, V., LEMOTTEE, J., and WICKRAMANAYAKE, T. W. 1950. Mineral metabolism on rice diets. Br. J. Nutr. 4:101.

DOBBS, R. J., and BAIRD, I. M. 1977. Effect of wholemeal and white bread on iron absorption in normal people. Br. Med. J. 2:1641.

DREWS, L. M., KIES, C., and FOX, H. M. 1979. Effect of dietary fiber on copper, zinc, and magnesium utilization by adolescent boys. Am. J. Clin. Nutr. 32:1893.

ELWOOD, P. C., BENJAMIN, I. T., FRY, F. A., EAKINS, J. D., BROWN, D. A., DEKOCK, P. C., and SHAH, J. U. 1970. Absorption of

iron from chapatti made from wheat flour. Am. J. Clin. Nutr. 23:1267.
GOERING, H. K., and VAN SOEST, P. T. 1970. Forage fiber analyses. Agric. Handbook No. 379. U.S. Government Printing Office: Washington, DC 20402.
GUTHRIE, B. E., and ROBINSON, M. F. 1978. Zinc balance studies during wheat bran supplementation. Fed. Proc. 37:254.
HAGHSHENASS, M., MAHLOUDJI, M., REINHOLD, J. G., and MOHAMMADI, N. 1972. Iron deficiency anemia in an Iranian population associated with high intakes of iron. Am. J. Clin. Nutr. 25:1143.
HALSTED, J. A., RONAGHY, H. A., ABADI, P., HAGHSHENASS, M., AMIRHAKEMI, G. H., BARAKAT, R. M., and REINHOLD, J. G. 1972. Zinc deficiency in man. The Shiraz experiment. Am. J. Med. 53:277.
HARLAND, B. F., STRINGFELLOW, D. E., CONNOR, D. H., FOSTER, W. D., and HEGGIE, C. M. 1979. Lowered plasma zinc in humans ingesting wheat bran products. Fed. Proc. 38:548.
HEATON, K. W., MANNING, A. P., and HARTOG, M. 1976. Lack of effect on blood lipid and calcium concentrations of young men on changing from white to wholemeal bread. Br. J. Nutr. 35:55.
HUSSAIN, R., and PATWARDHAN, V. N. 1959. The influence of phytate on the absorption of iron. Ind. J. Med. Res. 47:676.
ISMAIL-BEIGI, F., FARADJI, B., and REINHOLD, J. G. 1977a. Binding of zinc and iron to wheat bread, wheat bran, and their components. Am. J. Clin. Nutr. 30:1721.
ISMAIL-BEIGI, F., REINHOLD, J. G., FARADJI, B., and ABADI, P. 1977b. Effect of cellulose added to diets of low and high fiber content upon the metabolism of calcium, magnesium, zinc and phosphorus by man. J. Nutr. 107:510.
JAMES, W. P. T., BRANCH, W. J., and SOUTHGATE, D. A. T. 1978. Calcium binding by dietary fibre. Lancet 1:638.
JENKINS, D. J. A., HILL, M. S., and CUMMINGS, J. H. 1975. Effect of wheat fiber on blood lipids, fecal steroid excretion and serum iron. Am. J. Clin. Nutr. 28:1408.
KELSAY, J. L. 1978. A review of research on effects of fiber intake on man. Am. J. Clin. Nutr. 31:142.
KELSAY, J. L., BEHALL, K. M., and PRATHER, E. S. 1978. Effect of fiber from fruits and vegetables on metabolic responses of human subjects. I. Bowel transit time, number of defecations, fecal weight, urinary excretions of energy and nitrogen, and apparent digestibilities of energy, nitrogen, and fat. Am. J. Clin. Nutr. 31:1149.
KELSAY, J. L., BEHALL, K. M., and PRATHER, E. S. 1979a. Effect of fiber from fruits and vegetables on metabolic responses of human subjects. II. Calcium, magnesium, iron, and silicon balances. Am. J. Clin. Nutr. 32:1876.
KELSAY, J. L., CLARK, W. M., HERBST, B. J., and PRATHER, E. S. 1979b. Response of human subjects to three levels of fiber intake from fruits and vegetables. Fed. Proc. 38:767.
KELSAY, J. L., JACOB, R. A., and PRATHER, E. S. 1979c. Effect of fiber from fruits and vegetables on metabolic responses of human subjects. III. Zinc, copper, and phosphorus balances. Am. J. Clin. Nutr. 32:2307.
KIES, C., FOX, H. M., and BESHGETOOR, D. 1979. Effect of various levels of dietary hemicellulose on zinc nutritional status of men. Cereal Chem. 56:133.
MONSEN, E. R., HALLBERG, L., LAYRISSE, M., HEGSTED, D. M., COOK, J. D., MERTZ, W., and FINCH, C. A. 1978. Estimation of available dietary iron. Am. J. Clin. Nutr. 31:134.
PAPAKYRIKOS, H., KIES, C., and FOX, H. M. 1979. Zinc and magnesium utilization as affected by graded levels of hemicellulose, cellulose and wheat bran. Fed. Proc. 38:549.
PERSSON, I., RABY, K., FONNS-BECH, P., and JENSEN, E. 1975. Bran and blood-lipids. Lancet 2:1208.
PLANT, A., KIES, C., and FOX, H. M. 1979. The effect of copper and fiber supplementation on copper utilization in humans. Fed. Proc. 38:549.
REINHOLD, J. G., FARADJI, B., ABADI, P., and ISMAIL-BEIGI, F. 1976a. Decreased absorption of calcium, magnesium, zinc and phosphorus by humans due to increased fiber and phosphorus consumption as wheat bread. J. Nutr. 106:493.
REINHOLD, J. G., FARADJI, B., ABADI, P., and ISMAIL-BEIGI, F. 1976b. Binding of zinc to fiber and other solids of wholemeal bread. Page 163 in: Prasad, A. S., ed. Trace Elements in Human Health and Disease, Vol. 1. Academic Press: New York.
REINHOLD, J. G., HEDAYATI, H., LAHIMGARZADEH, A., and NASR, K. 1973a. Zinc, calcium, phosphorus, and nitrogen balances of Iranian villagers following a change from phytate-rich to phytate-poor diets. Ecol. Food Nutr. 2:157.
REINHOLD, J. G., ISMAIL-BEIGI, F., and FARADJI, B. 1975. Fibre vs. phytate as determinant of the availability of calcium, zinc and iron of breadstuffs. Nutr. Rep. Int. 12:75.
REINHOLD, J. G., NASR, K., LAHIMGARZADEH, A., and HEDAYATI, H. 1973b. Effects of purified phytate and phytate-rich bread upon metabolism of zinc, calcium, phosphorus, and nitrogen in man. Lancet 1:283.
SANDSTEAD, H. H., MUNOZ, J. M., JACOB, R. A., KLEVAY, L. M., RECK, S. J., LOGAN, G. M., Jr., DINTZIS, F. R., INGLETT, G. E., and SHUEY, W. C. 1978. Influence of dietary fiber on trace element balance. Am. J. Clin. Nutr. 31:S180.
VELLAR, O. D., BORCHGREVINK, C., and NATVIG, H. 1968. Iron fortified bread. Absorption and utilization studies. Acta Med. Scand. 183:251.
WALKER, A. R. P., FOX, F. W., and IRVING, J. T. 1948. Studies in human mineral metabolism. I. The effect of bread rich in phytate phosphorus on the metabolism of certain mineral salts with special reference to calcium. Biochem. J. 42:452.
WIDDOWSON, E. M., and McCANCE, R. A. 1942. Iron exchanges of adults on white and brown bread diets. Lancet 1:588.

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