Decreased Absorption of Calcium, Magnesium, Zinc and Phosphorus by Humans due to Increased Fiber and Phosphorus Consumption as Wheat Bread

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ABSTRACT During a 20 day period of high fiber consumption in the form of bread made partly from wheaten wholemeal, two men developed negative balances of calcium, magnesium, zinc and phosphorus due to increased fecal excretion of each element. The fecal losses correlated closely with fecal dry matter and phosphorus. Fecal dry matter, in turn, was directly proportional to fecal fiber excretion. Balances of nitrogen remained positive. Mineral elements were well-utilized by the same subjects during a 20 day period of white bread consumption. J. Nutr. 106: 493-503, 1976.

INDEXING KEY WORDS bread · calcium · fiber · magnesium · phosphorus · zinc

The staple food in Iran, as elsewhere in the Middle East and in Northern India, is bread made from wheat flours of varying degrees of refinement. In Iranian cities, the breads consumed are made almost entirely from flours of 80% to 90% extraction rate into leavened flat breads, Bazari (or Tafton) and Sangak. Outside of the cities and larger towns, locally ground wholemeals of nearly total extraction rate are made mainly into the paper-thin shepherds breads, Tanok or Lavosh. Leaven is often omitted in their preparation, but when used, limited fermentation occurs partly because of the brief time allowed and also because of the resistance of wholemeals to the action of yeast (1). Kouhestani et al. (2) have described the preparation of various traditional Iranian breads. The nutritional properties of these and similar breads affect the well-being of a very large population.

All rural and most urban breads consumed in these regions contain substantial amounts of fiber. They also include significant amounts of phytate, averaging 0.7% by weight in the rural and about half this concentration in urban breads. This difference results in part from the use of somewhat lower extraction flours by city bakers but mainly from destruction of phytate by sourdough organisms of leaven (3). Fiber concentrations of the various breads differ less than those of phytate and fiber intakes are consistently high. Maleki (4) found at least 50% of the energy intake of village schoolboys in Iran to be derived from bread, but the proportion approaches 75% or more in both village and urban families.

A suspicion that the high intakes of breads of these types were not entirely beneficial arose during investigations of the cause of the hypogonadal dwarfism

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that is a manifestation of zinc deficiency. This syndrome is seen only among adolescent groups in various villages and consumption of wholemeal breads in large amounts appeared to be causally important (5, 6). Although village breads and the village diet contain enough zinc, iron, and calcium to fulfill daily requirements for these metals (4, 7), their availability for intestinal absorption is poor. As a result, in addition to zinc deficiency, iron (7) and calcium deficiencies (8) also exist. Those of zinc and iron respond to supplementation with these metals (7, 9). The response to calcium supplementation is not as well-documented. However, when villagers after a lifelong consumption of wholemeal bread consumed diets that supplied ample amounts of calcium, zinc and phosphorus in available forms, they retained abnormally high proportions of each element, although not of nitrogen (10). The magnitude of these retentions suggested that body stores of the mineral elements were depleted, and that increased risk of the development of mineral deficiencies may be postulated. Our previous studies have been concerned with wholemeal bread, however, a close similarity in composition made it necessary to obtain additional information about the effects of consumption of bread made from flour of somewhat lower extraction rates upon mineral metabolism. In this paper we describe the response of two human subjects to the consumption of such a bread, Bazari, made from flour of 80% to 90% extraction rate with that of white bread.

METHODS

Subjects. Experiments were carried out on two men who were fully informed as to the studies to be made and their objectives. Subject Rah had participated in two previous long-term metabolic experiments. He was a 35-year-old itinerant barber, and his friend, subject Mor was a 24-year-old unemployed laborer. Both sold blood occasionally to the Hospital Blood Bank, although neither had donated recently, and their hemoglobin concentrations were 13.0 and 12.7 g/100 ml respectively. They weighed 56.0 and 60.3 kg. Body weights were normal for heights (158 and 163 cm) and neither subject showed evidence of malnutrition. Their diets before admission consisted predominantly of leavened flat breads of the type under investigation. Both ate meat two or three times a week and eggs about as often but consumed fruit daily in large amounts. Clinical and laboratory examination disclosed no signs of disease.

The men were housed for the study in a metabolism ward along with other patients and were assigned light duties in the ward and laboratory to provide exercise and decrease boredom. They were allowed to leave the hospital one afternoon each week. An enclosed garden adjoining the ward permitted exposure to the sun about 30 minutes daily. Three times each day they were instructed to climb four flights of stairs to further forestall effects of inactivity.

After admission, they received the general hospital diet for 1 week. The diet was then modified during the next 20 days so that somewhat more than 50% of their energy intake was provided by white bread. A second 20-day period followed in which Bazari bread replaced the white bread.* Diets are described in table 1. Meals were assembled by a trained assistant who weighed the required amounts of foods. A duplicate meal was prepared at the same time and refrigerated for later analysis. Food quantities in the duplicate meal were those required by subject Rah. The additional requirements of subject Mor based on body weight were supplied by an extra 100 g of bread daily. Corrections were made for the infrequent occasions when a meal was not eaten completely.

Drinking water in central Iran is rich in minerals and metals and makes an appreciable contribution to total intakes. Measurements of water consumption proved to be unreliable. Instead, intakes were esti-

* The Bazari bread was supplied by a local bakery. It was made from wheat flour of 90% to 95% extraction using a sourdough leaven and is similar to the Taftoon described by Koubastin et al. (2). Samples of Bazari taken at random from that served our subjects contained in air-dried samples: calcium, 511 ± 67; magnesium, 1,066 ± 84; zinc, 11.1 ± 3.2; phosphorus, 900 ± 60 mg/kg (means ± SD of six samples). Phytate concentrations averaged 0.33% and fiber 3.9%. Average loss of weight on drying in air at room temperature was 20.6%. The white bread served was made in a small bakery by a double fermentation pan baking process from flour of about 70% extraction rate. Bakers yeast was used as leaven. Analyses of six samples showed its composition to be close to that tabulated for Western white bread.
mated from the 24 hour urine volume on the assumption that water generated from metabolism balanced insensible losses. An adjustment was made for the 800 ml of tea and milk consumed daily. A single water cooler served as the source of drinking water which contained an average of 0.44 mg of zinc, 40 mg of calcium and 42 mg of magnesium per liter.

Five hundred milligrams of chromic oxide were mixed into one dish of each of the meals, starting 1 day before fecal collections were started and continued daily thereafter. The chromic oxide had been purified by extraction with concentrated hydrochloric acid (11), pulverized and passed through a 60 mesh per inch sieve.

Analytical procedures. The duplicate diets of 2 consecutive days were combined and weighed. Distilled water (four times the food weight) was added and the mixture homogenized in a large blender. Fecal collections were made in widemouth polyethylene containers. Collections for 2 days were combined, weighed, diluted with an equal weight of distilled water and dispersed in a high speed vibrating paint mixer. Samples of diets and feces were preserved with the aid of toluene and refrigeration in polyethylene containers shown by test to be free of leachable zinc.

Diet and feces samples were thoroughly dispersed before sampling with the aid of a mechanical stirring apparatus. Using a zinc-free polyethylene syringe, 4 to 6 drops were transferred to tared acid washed digestion tubes or Kjeldahl flasks of 30 ml capacity (for nitrogen). Tubes and flasks were weighed and weight of samples calculated by the difference. HNO₃ was added to the contents of the digestion tubes together with acid-washed glass beads. After standing overnight, the HNO₃ was boiled off and ashing completed with the aid of 60% HClO₄. The HClO₄ in turn was fumed off, leaving about 0.05 ml in the tube to insure complete solubility in the 5.0 ml of deionized water added. After appropriate dilution with LaCl₃ solution, concentrations of Ca, Mg and Zn were measured by atomic absorption spectrometry. Instrument settings used were those recommended by the manufacturer (12). Plasma was diluted 1:3 with doubly distilled water and urine acidified and diluted 1:10 or 1:20 with La solution. Serum phosphorus concentrations were measured photometrically following reduction of phosphomolybdate by means of 2% ascorbic acid solution.

Samples for Cr analysis were ashed separately and Cr was measured as dichromate by the method of Bolin et al. (13) with modifications recommended by Day (14). The recovery of Cr₂O₃ in the feces averaged 1,425 mg during periods when no losses of feces occurred. Fecal excretions of the elements studied were corrected by multiplying the factor 1,425/Cr₂O₃ where Cr₂O₃ is the weight in mg of the Cr₂O₃ found in a 24 hour collection. The loss of some Cr₂O₃ is attributed mainly to a small residue that escaped ingestion, however, others (10) have experienced small losses of chromic oxide added to the diet as a marker.

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Diets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weight</td>
</tr>
<tr>
<td>Breakfast</td>
<td></td>
</tr>
<tr>
<td>Bread, white, or Bazari</td>
<td>150</td>
</tr>
<tr>
<td>Cheese, white</td>
<td>50</td>
</tr>
<tr>
<td>Milk</td>
<td>200</td>
</tr>
<tr>
<td>Sucrose</td>
<td>15</td>
</tr>
<tr>
<td>Noon meal</td>
<td></td>
</tr>
<tr>
<td>Bread, white, or Bazari</td>
<td>150</td>
</tr>
<tr>
<td>Mutton, lean</td>
<td>50</td>
</tr>
<tr>
<td>Rice, white</td>
<td>65</td>
</tr>
<tr>
<td>Dried beans</td>
<td>50</td>
</tr>
<tr>
<td>Corn oil</td>
<td>10</td>
</tr>
<tr>
<td>Lettuce, etc.</td>
<td>100</td>
</tr>
<tr>
<td>Fruit</td>
<td>100</td>
</tr>
<tr>
<td>Sucrose</td>
<td>15</td>
</tr>
<tr>
<td>Evening meal</td>
<td></td>
</tr>
<tr>
<td>Bread, white, or Bazari</td>
<td>200</td>
</tr>
<tr>
<td>Turnips, beets, carrots or onions</td>
<td>100</td>
</tr>
<tr>
<td>Potatoes, white</td>
<td>100</td>
</tr>
<tr>
<td>Lettuce, etc.</td>
<td>100</td>
</tr>
<tr>
<td>Fruit</td>
<td>100</td>
</tr>
<tr>
<td>Sucrose</td>
<td>10</td>
</tr>
</tbody>
</table>

**| 58.3% of total energy supplied by bread. | 62.3% of total energy supplied by bread. |

* Model 303, The Perkin Elmer Corp., Norwalk, Conn., U.S.A.
Fiber contents of diets and feces were measured by two methods. Originally, the Weende method (15) was used but this was replaced by the acid-detergent (A-D) method (16) when chemicals became available for the latter. The A-D method avoids the partial destruction of some fiber components caused by the treatment with alkali in the older method. It was found that the drying procedure was critical in application of the A-D method and that low values resulted when this was done at 60° or above. Consequently, temperatures during drying were kept below 40° by a procedure that included decantation of free water after centrifugation and two successive extractions with acetone each in volume roughly equal to that of the original sample of diluted diet. The acetone also was removed by decantation after centrifugation, and finally by evaporation to constant weight in a heating block at 40°. The weight of the dry residue provided an estimate of total solids. The residue was extracted with diethyl ether for 4 hours in a Soxhlet. Ether was removed by evaporation and 1.0 g samples digested with 100 ml of boiling cetyltrimethylammonium bromide, 2% W/V in 1 N H2SO4 for 1 hour. Filtration of fiber residue through sintered glass was too slow to be practicable. Instead, the fiber was separated by centrifugation in tared glass centrifuge tubes. It was washed with boiling water, centrifuged, and washed finally with acetone before being dried to constant weight at 60°. Fecal fiber was less susceptible to damage by heat and fecal samples could be dried at 60° without washing with acetone and without decrease in yield.

The Weende method was less troublesome in application. Filtration through fritted glass caused no difficulty. Both methods demonstrated a marked increase in dietary and fecal fiber associated with the consumption of Bazari bread. However, values yielded by the A-D method were nearly double those of the Weende method. Only the results obtained by the A-D method are presented.

Phytate concentrations were measured according to Oberleas (17) except that separations were made by centrifugation instead of filtration.

Ten milliliters of blood was collected and half added to a polyethylene tube containing 1 drop of sodium citrate trihydrate, 20% w/v. Plasma from this portion was used for measurement of calcium, magnesium and zinc concentrations. The citrate prevents changes in zinc concentration that accompany clotting and results in a higher yield of plasma with less likelihood of hemolysis than does blood permitted to clot. The remainder of the blood was allowed to clot and its serum was used to measure alkaline phosphatase (18), albumin (19), total protein (20), and P concentrations. With the exception of P none showed significant changes during the study periods and the results are omitted. Iron intakes and excretions, serum iron and hemoglobin concentrations in blood were also examined. These together with data from other experiments are to be presented later. Blood collections were made initially and at approximately weekly intervals. Nitrogen in diets and excreta was determined by a micro-Kjeldahl method using mercury as a catalyst (22).

Statistical methods used are described by Klugh (21).

RESULTS

Fiber intake and output. The mean fiber intake of subject Rah rose by 34% and that of subject Mor by 54% when Bazari replaced white bread in their diets (table 2). The increase in weight of fecal fiber was less than that of dietary fiber intake. Discrepancies may be the result of partial destruction of food fiber by the bacteria of the large gut. The extent of destruction varies in different individuals (23).

Fecal output. The mass of feces increased substantially in both subjects during the period of Bazari consumption as compared with that excreted during the white bread period (table 2). Wet and dry weights both rose substantially but the relationship between the two differed in the two subjects. Although the increase in fecal dry matter was considerably larger than that of fecal fiber, the two were closely related.

Zinc. Positive balances established during the period of white bread consumption became negative when Bazari replaced the
## TABLE 2

### Dietary and fecal fiber and fecal wet and dry weights

<table>
<thead>
<tr>
<th>Date</th>
<th>Diet Fiber</th>
<th>Wet g/24 hr</th>
<th>Dry g/24 hr</th>
<th>Low fiber diet</th>
<th>Wet g/24 hr</th>
<th>Dry g/24 hr</th>
<th>High fiber diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oct. 16</td>
<td>18</td>
<td>125</td>
<td>14</td>
<td>2.6</td>
<td>18</td>
<td>15</td>
<td>1.2</td>
</tr>
<tr>
<td>18</td>
<td>19</td>
<td>165</td>
<td>19</td>
<td>3.9</td>
<td>24</td>
<td>280</td>
<td>21</td>
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<tr>
<td>20</td>
<td>21</td>
<td>175</td>
<td>14</td>
<td>2.8</td>
<td>19</td>
<td>240</td>
<td>9</td>
</tr>
<tr>
<td>22</td>
<td>22</td>
<td>190</td>
<td>26</td>
<td>6.2</td>
<td>22</td>
<td>260</td>
<td>10</td>
</tr>
<tr>
<td>24</td>
<td>24</td>
<td>240</td>
<td>16</td>
<td>3.0</td>
<td>24</td>
<td>310</td>
<td>18</td>
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<tr>
<td>26</td>
<td>27</td>
<td>275</td>
<td>25</td>
<td>5.1</td>
<td>27</td>
<td>240</td>
<td>21</td>
</tr>
<tr>
<td>28</td>
<td>28</td>
<td>200</td>
<td>18</td>
<td>3.7</td>
<td>22</td>
<td>350</td>
<td>21</td>
</tr>
<tr>
<td>30</td>
<td>29</td>
<td>235</td>
<td>25</td>
<td>4.8</td>
<td>29</td>
<td>370</td>
<td>18</td>
</tr>
<tr>
<td>Nov. 1</td>
<td>30</td>
<td>205</td>
<td>24</td>
<td>6.1</td>
<td>20</td>
<td>350</td>
<td>23</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>240</td>
<td>24</td>
<td>7.0</td>
<td>16</td>
<td>340</td>
<td>24</td>
</tr>
<tr>
<td>Mean</td>
<td>21.9</td>
<td>±1.6</td>
<td>±7.5</td>
<td>±1.5</td>
<td>21.9</td>
<td>±1.6</td>
<td>±6.6</td>
</tr>
<tr>
<td>±SE</td>
<td>±1.5</td>
<td>±1.5</td>
<td>±1.5</td>
<td>±1.5</td>
<td>±1.5</td>
<td>±1.5</td>
<td>±1.5</td>
</tr>
</tbody>
</table>

**Significance of difference between the two diets evaluated by the Student t test with adjustment for sample size:**

- *P < 0.01.
- † *P < 0.001.

White bread (figs. 1 and 2, table 3). Increased fecal excretion was responsible for the change in balances. The mean balances of zinc during the two periods differed significantly for both subjects. Plasma zinc concentrations were initially normal (87 μg/100 ml in both). They had risen to 96 and 94 μg/100 ml in Rah and Mor respectively at the end of the study. Urinary excretion of zinc did not change.

**Calcium.** A significant increase in fecal excretion of calcium occurred following the change from white bread consumption to Bazari in both subjects (figs. 1 and 2, table 3). At the same time, excretion of calcium in urine decreased although not sufficiently to prevent a change in calcium balances from positive to negative in subject Rah and to more negative values in subject Mor. The changes took place despite moderately increased calcium intakes.

Subject Mor's plasma calcium concentrations was 8.8 mg/100 ml at the start. It rose to 9.6 mg/100 ml during the white bread feeding then fell to 9.0 mg/100 ml and finally to 8.8 mg/100 ml during the last 2 weeks of high fiber intake. The latter value borders on the abnormal. Plasma calcium concentration of subject Rah fluctuated between 8.8 and 9.0 mg/100 ml.

**Magnesium.** The high content of magnesium in Bazari led to a nearly doubled intake during its consumption compared with white bread. However, magnesium excretion in feces increased to a still greater extent while that in urine also rose sub-
stantially (figs. 1 and 2, table 3). Moderately negative magnesium balances resulted while Bazari was being consumed.

**Phosphorus.** Phosphorus intake increased by approximately one-third with replacement of white bread by Bazari bread in the diet. This was accompanied by a threefold rise in the excretion of phosphorus in the feces (figs. 1 and 2, table 3). Excretion in the urine by Subject Mor increased markedly and remained high when Bazari was consumed. Subject Rah did not respond with increased phosphorus excretion in urine. Nevertheless, phosphorus balances of both subjects changed from markedly positive to negative with the change being

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**Fig. 1** Metabolic balances of subject Rah during consumption of a mixed diet for 20 days in which about 60% of the energy was supplied by white bread followed by a second 20-day period when white bread was replaced in the same proportion by Bazari bread made from wheat flour of high extraction rate. Each rectangle represents a 2-day interval. Units are mg/24 hour. Crosshatched areas show excretion in feces, clear areas in urine.
especially large in Subject Mor. In serum, Mor's phosphorus concentrations which had risen from 3.0 to 3.5 mg/100 ml during white bread consumption, fell to 3.1 mg/100 ml after 1 week of Bazari consumption and then rose again to 3.5 mg/100 ml. In Rah's serum, phosphorus concentrations also rose from 3.5 to 4.1 mg/100 ml during consumption of white bread. The change to Bazari feeding was followed by a decrease to 3.8 mg/100 ml after 1 week and a later rise to 4.0 mg/100 ml at the end of the study.

Nitrogen. Nitrogen excretion in feces increased by about 0.5 g daily in both subjects when Bazari replaced white bread in
Because of magnesium by incorporation of zinc, both concentrations increased. The excretion of nitrogen, phosphorus and magnesium was inferior to the latter as a source of these nutrients. Poor availability, as shown by increased fecal losses of zinc, calcium, magnesium and phosphorus that accompanied Bazari consumption is the reason. The decrease in Mor's plasma calcium concentration is further evidence that the diet (Table 3). The change in the mean excretion was significant in both subjects. A small gain in nitrogen balance by Mor was not statistically significant. No changes occurred in total protein or albumin concentrations of serum in either subject and both were within the limits found in healthy well-nourished persons.

**Body weight.** Subject Rah gained 0.8 kg and Mor lost 1.0 kg during the 40 day study.

**DISCUSSION**

Bazari bread contains somewhat more zinc and calcium and much more magnesium and phosphorus than white bread, yet our findings indicate that it is nutritionally inferior to the latter as a source of these nutrients. Poor availability, as shown by increased fecal losses of zinc, calcium, magnesium and phosphorus that accompanied Bazari consumption is the reason. The nutritional significance of the increased fecal losses will depend upon their duration. Some evidence of adaptation may be seen in Rah, for example, whose zinc balances became less negative during the final 10 days of Bazari consumption and whose phosphorus balances also improved. However, no improvement in calcium and magnesium balances occurred in either subject. The decrease in Mor's plasma calcium concentration is further evidence that

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**Table 3**

*Metabolic behavior during low and high fiber consumption during ten 2-day periods*

<table>
<thead>
<tr>
<th>Subject</th>
<th>Bread</th>
<th>Intake</th>
<th>Urine</th>
<th>Feces</th>
<th>Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc mg/24 hr</td>
<td>Rah White</td>
<td>18.1 ± 0.81</td>
<td>0.7</td>
<td>15.8 ± 0.62</td>
<td>+ 1.6</td>
</tr>
<tr>
<td></td>
<td>Bazari White</td>
<td>19.0 ± 0.36</td>
<td>0.7</td>
<td>20.7 ± 0.76</td>
<td>- 2.4</td>
</tr>
<tr>
<td></td>
<td>Mor White</td>
<td>19.4 ± 0.81</td>
<td>0.7</td>
<td>18.3 ± 0.94</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Bazari White</td>
<td>19.4 ± 0.41</td>
<td>0.8</td>
<td>20.1 ± 0.45</td>
<td>- 1.5</td>
</tr>
<tr>
<td>Calcium mg/24 hr</td>
<td>Rah White</td>
<td>733 ± 19.7</td>
<td>154 ± 10.5</td>
<td>522 ± 51</td>
<td>+ 57</td>
</tr>
<tr>
<td></td>
<td>Bazari White</td>
<td>784 ± 17.1</td>
<td>99 ± 4.6</td>
<td>846 ± 20</td>
<td>- 161</td>
</tr>
<tr>
<td></td>
<td>Mor White</td>
<td>772 ± 15.7</td>
<td>187 ± 7.9</td>
<td>625 ± 35</td>
<td>- 40</td>
</tr>
<tr>
<td></td>
<td>Bazari White</td>
<td>841 ± 18.2</td>
<td>128 ± 5.0</td>
<td>835 ± 32</td>
<td>- 122</td>
</tr>
<tr>
<td>Magnesium mg/24 hr</td>
<td>Rah White</td>
<td>348 ± 12.0</td>
<td>170 ± 6.9</td>
<td>188 ± 11.6</td>
<td>- 10</td>
</tr>
<tr>
<td></td>
<td>Bazari White</td>
<td>650 ± 19.5</td>
<td>210 ± 10.5</td>
<td>484 ± 34</td>
<td>- 44</td>
</tr>
<tr>
<td></td>
<td>Mor White</td>
<td>380 ± 10.6</td>
<td>185 ± 4.4</td>
<td>191 ± 13.4</td>
<td>+ 4</td>
</tr>
<tr>
<td></td>
<td>Bazari White</td>
<td>724 ± 41.7</td>
<td>235 ± 6.9</td>
<td>618 ± 44.3</td>
<td>- 129</td>
</tr>
<tr>
<td>Phosphorus mg/24 hr</td>
<td>Rah White</td>
<td>1288 ± 49.4</td>
<td>764 ± 51</td>
<td>346 ± 38</td>
<td>+ 178</td>
</tr>
<tr>
<td></td>
<td>Bazari White</td>
<td>1740 ± 58.0</td>
<td>654 ± 69</td>
<td>1118 ± 104</td>
<td>- 32</td>
</tr>
<tr>
<td></td>
<td>Mor White</td>
<td>1400 ± 51</td>
<td>887 ± 24</td>
<td>287 ± 15</td>
<td>+ 226</td>
</tr>
<tr>
<td></td>
<td>Bazari White</td>
<td>1940 ± 38</td>
<td>1240 ± 75</td>
<td>948 ± 81</td>
<td>- 248</td>
</tr>
<tr>
<td>Nitrogen g/24 hr</td>
<td>Rah White</td>
<td>15.5 ± 0.3</td>
<td>12.5 ± 0.4</td>
<td>2.3 ± 0.1</td>
<td>+ 0.7</td>
</tr>
<tr>
<td></td>
<td>Bazari White</td>
<td>16.0 ± 0.3</td>
<td>12.5 ± 0.4</td>
<td>2.8 ± 0.1</td>
<td>+ 0.7</td>
</tr>
<tr>
<td></td>
<td>Mor White</td>
<td>17.0 ± 0.3</td>
<td>14.8 ± 0.5</td>
<td>2.4 ± 0.2</td>
<td>- 0.2</td>
</tr>
<tr>
<td></td>
<td>Bazari White</td>
<td>17.5 ± 0.3</td>
<td>14.2 ± 0.5</td>
<td>3.0 ± 0.1</td>
<td>+ 0.3</td>
</tr>
</tbody>
</table>

*Mean ± SEM.  *Significance of differences between the means of the low fiber (white bread) and high fiber (Bazari bread) periods estimated by the t test.  $P < 0.01$.  $P < 0.001$.
the effects of Bazari consumption were persisting. Our impression derived from similar experiments extending over periods of 2 months or more is that adaptation is selective and incomplete. This belief is supported by the balance studies of Iranian villagers previously mentioned (10).

Interference with absorption of bivalent metals by cereal grains has been attributed to their high content of phytate. Poorly soluble complexes of phytate with bivalent metals exist in wheat (24). However, phytate is digestible by the rat and almost certainly in man, although the extent of its digestibility in man remains to be determined. Nevertheless, the phosphorus released by digestion of phytate can also form complexes with bivalent metals and decrease their availability.

Several findings create doubt as to whether phytate is the sole or even the most important complexant of bivalent metals in wheat flours of high extraction rates. An increase in solubility and availability of zinc in wholemeal bread as a result of the action of yeast leaven far exceeded expectations based upon observed destruction of phytate (25). Studies in vitro in which phytate was removed from wholemeal or bran by extraction with acid or by action of phytase (meso-inositol-hexaphosphate phosphohydrolase, EC 3.1.3.8) brought about increased binding of metals instead of the expected decrease (23). These and other observations led us to conclude that the fiber of wheat was largely responsible for metal binding. Celulose has been shown to interfere with absorption of zinc (26).

The potent effects of Bazari consumption, a bread of moderate phytate content, upon mineral metabolism are similar to those observed when Tanok, a village bread of much higher phytate but similar fiber content, was consumed (27).

While fiber intake increased by one-third and one-half respectively in the two subjects when Bazari replaced white bread in the diet, outputs of fiber in feces increased twofold and threefold. It appears from this that fiber of wheat is more resistant to degradation by the intestinal flora than that derived from other foods. However, it is also possible that an increased fiber mass in the presence of a limited capacity for degradation may explain these effects.

The increase in fecal wet weight that followed the rise in fiber intake differed in the two subjects, a difference that may also depend upon the extent of bacterial degradation of fiber in the large intestine. Presumably, production of water-soluble but unabsorbable saccharide degradation products from fiber are important determinants of fecal wet weight. Polysaccharides of this type would escape measurement by the procedure used for fiber analysis.

A correlation between fecal dry matter and excretion of zinc has been observed (28). The relationship is confirmed by our data. In addition, these show a similar close relationship between dry matter and calcium and magnesium excretion in feces. However, the content of dry matter in feces depends directly upon the fiber intake and fiber content of feces. The fundamental relationship, therefore, appears to be between metal and fiber. Highly significant correlations between fiber and metal excretions are shown in Table 4.

The change from white bread consumption to Bazari bread and the accompanying rise in phosphorus intake was followed by considerably increased fecal excretion of phosphorus. Phosphorus, whether as phytate, its decomposition products, or inorganic phosphate readily forms poorly soluble complexes with zinc at the pH of the intestinal contents (29) and presumably with calcium and magnesium. Correlations between fecal phosphorus and calcium, magnesium and zinc excretions, like those of fiber, are also highly significant. One may conclude, therefore, that both fiber and phosphorus complex metals in the small intestine and that phosphorus which escapes absorption carries a quota of metal into the large gut and the feces. Correlation between fiber and phosphorus in the feces is not as close as or as consistent as that of either with the bivalent metals. Indeed, the coefficient of correlation became nega-
tive in subject Rah during the period of Bazari consumption.

Increased intakes of fiber as wheat flour are accompanied by a decrease in digestibility (30), and this association is also shown by the increased fecal nitrogen excretion that occurred. Highly significant correlations between fecal fiber and nitrogen excretion existed in both subjects.

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