In Vitro Mineral-Binding Capacity of Various Fibre Sources: The Monogastric Sequential Simulated Physiological Conditions

H. R. Hemati Matin, F. Shariatmadari * and M. A. Karimi Torshizi

School of Agriculture, Tarbiat Modares University, Tehran-Iran, 14115-336
* Corresponding author: e-mail: shariatf@modares.ac.ir

Abstract. This study was conducted to investigate the in vitro mineral-binding capacity (MBC) of some synthetic fibre sources under sequential simulated physiological conditions (SSPC) of mono-gastrointestinal tract (GIT). Arbocel and pectin suspensions were acidic (~3.9), whereas those of cellulose, carboxymethyl cellulose, and Vitacel were slightly basic (~7.5). Pectin and carboxymethyl cellulose induced higher viscosity than other fibre suspensions. All fibre sources exhibited low levels of endogenous Ca and Mg, and very low levels of endogenous Fe, Cu, and Zn. Most of endogenous Ca, Mg (>90%), and Zn (>70%) of fibre sources were removed under the conditions of stomach. Except for Ca, the in vitro MBC of tested fibre sources was low. Under the conditions of the colon (pH 5.80), only bound Zn was readily released. Thus, the MBC of fibre sources has no detrimental effects on mineral bioavailability (except for Ca).

Keywords: In vitro mineral-binding capacity; simulated mono-gastrointestinal conditions; fibre
1. INTRODUCTION

Fibres are beneficial for preventing wide range of GIT diseases [4], diet dilution, plasma lipid reduction, diverticulosis [2], cardiovascular diseases, promoting normal laxation [19] and reducing pathogenic agents in GIT. This cause new production of fibre considers by fibre mills each day. Besides this issue, their potential detrimental effects of fibre sources include compromising caloric regulation [27] and reducing bioavailability of essential minerals, trace elements [30], vitamins, and bile acids. This topic can undermine the benefits of the fibre sources.

The issue of the influence of fibre sources on mineral bioavailability has been subject of many investigations [7, 13, 14, 15, 17, 18]. Due to the various properties of fibre sources [7, 29], functional groups in mineral-fibre interactions, type and concentration of fibre sources, and other components of diets [9] have led to conflicting results. Thus, drawing an obvious conclusion about the subject is difficult.

The postulates of electrostatic binding and/or trapping of minerals within fibre particles are believed to be the main factors determining mineral bioavailability [29]. Investigation of such interactions by in vivo experiments is costly and time consuming. Furthermore, the results are often variable and difficult to interpret because factors such as different GIT conditions or animal-related factors. Conducting such experiments could also compromise the health of the animal and human subjects. Therefore, conducting in vitro investigations on the MBC of fibre sources is preferable in attempt to understand the effect of fibre sources on mineral bioavailability.

Previous studies have examined different natural fibre sources and their binding capacity for only a few minerals [6, 7, 13]. In most of these studies, the physiological pH was considered 6.5, while researchers adopted a pH of 5.8 [29]. They argued that changes that occur during fermentation should be taken into consideration, and that a physiological pH of 5.8 is more realistic. At this pH, the probability is high that bound minerals would be released from the fibre sources into the colon.

In vitro methods for studying the MBC of fibre sources under SSPC of the GIT have been well developed [9, 14, 15]. Synthetic fibre sources achieved more attention in recent years. Recommendations were paid on their use in diets due to their positive roles in digestive functions [8, 12]. But, little scientific literature exists that examines their interaction with mineral. Therefore, the main purpose of the present study was to evaluate the in vitro binding capacity of some purified synthetic fibre sources (i.e. pectin, cellulose and carboxymethyl cellulose, Arbocel, and Vitace1) to important divalent minerals (i.e. Ca, Mg, Cu, Fe, and Zn) under SSPC of mono-GIT.
2. MATERIALS AND METHODS

2.1. Materials
Cellulose, carboxymethyl cellulose, Arbocel, and Vitacel were prepared from J. Rettenmaier & Sohne GmbH+Co, and pectin from HP, USA companies.

2.2. Analytical Methods
The chemical compositions of fibre sources were determined following the general procedures described by the Association of Official Analytical Chemists [1] with slight modifications as described below. The moisture contents of various fibre sources were determined by heating 1 g of each sample in an oven for 16 h at 105 °C followed by heating at 130 °C for 2 h. The ash content was determined in a muffle furnace by slowly heating 2 g of each sample up to 500 °C for 16 h [7]. The protein content of the fibre sources was estimated (N × 6.25) from the quantitative analysis of nitrogen with the Kjeldahl method.

2.3. Viscosity and pH Measurement
The viscosities of 0.1% (w/v) aqueous were determined at 25 °C by using a viscometer (Brookfield, LD) previously calibrated with a silicone standard. The pH values of 0.1% (w/v) fibre suspensions were determined at 25 °C with a calibrated pH meter (Metrohm, Germany).

2.4. In vitro Mineral-Binding Capacity
The in vitro MBC of the 5 fibre sources to Ca, Mg, Cu, Fe, and Zn was studied under SSPC of MGIT according to Idouraine et al. [15] with modifications based on Wong and Peter method [29]. Briefly, 25 g of each original fibre sample was gently shaken in 1% HCl solution (pH 1.5; ionic strength 75 mM KCl; 1:20 w/v) in a 600 mL beaker for a period of 3 h at 37 °C, in order to simulate the physiological conditions of the stomach (acid-washed fibre stimulation). The obtained slurry was then filtered through a Whatman 541 ashless filter paper, and the residue was washed several times with ultrapure water until the filtrate slurry was neutral (pH 7). All fibre samples treated in gastric conditions were then freeze-dried and 4.5-g fractions were kept for analysis of minerals. For determining the MBC under simulated physiological conditions of the small intestine, a 4-g fraction of each remaining gastric-condition-treated fibre sample was separately mixed with 40 mL of Ca, Mg, Cu, Fe, and Zn standard solutions (1000 mg/L each) (Ca: calcium carbonate; Mg: magnesium sulphate; Cu: copper sulphate; Fe: iron sulphate; and Zn: zinc sulphate; Merck, Germany) in a 500 mL Erlenmeyer flask. The volume of the mixture was then made up to 400 mL by adding 2.0 mM MES buffer solution (pH 6.8; ionic strength 100 mM KCl), and the sample was incubated at 37 °C for 3 h with light shaking. The slurry was then centrifuged at 2500 × g for 15 min at 25 °C. The supernatant was discarded, and the residue was washed several times with ultrapure water.
Subsequently, each fibre sample treated using small intestine conditions was freeze-dried, and 1.5-g portions were kept for the mineral analysis. Finally, to determine the MBC under simulated physiological conditions of the colon with a slightly acidic pH (re-acid washed), 2-g portions of the mineral-bound fibre sources treated using simulated small intestine physiological conditions were incubated with the 2.0 mM MES buffer solution (pH 5.8; ionic strength 100 mM KCl; 1:100, w/v) in a 250 mL Erlenmeyer flask for 24 h at 37 °C. The slurry was centrifuged at the above-mentioned conditions, and the residue was washed several times with ultrapure water until it became neutral (pH 7). All fibre sources treated under colonic conditions were then freeze-dried and 1.5-g portions were kept for the mineral analysis.

2.5. Mineral Determination

To determine the mineral composition of original (endogenous), acid-washed, mineral bound, and re-acid-washed fibre sources, duplicate samples (0.5 g) were wet ashed, and the concentrations of 5 minerals (Ca, Mg, Cu, Fe, and Zn) were analysed according to the modified AOAC method [1] based on Idouraine et al. [15]. Briefly, 5 mL nitric acid (65%) was added to samples in 25 mL digestion tubes. The pre-digested samples were heated for 1 h at 60 °C, then the temperature was raised to 100 °C and hydrogen peroxide (30%) was added to the tubes. The shift to a light green colour of the solutions indicated complete digestion. The Ca, Mg, Cu, Fe, and Zn concentrations in the ash solutions were then analysed using an atomic absorption spectrometer (Spectro AA, VARIAN). Finally, after determining the concentrations of minerals in endogenous and treated (stomach-, small intestine-, and colon-condition-treated) fibre sources, the percentages of the removed, bound, and released minerals were calculated by the following formulae:

\[
\% \text{ removed } = \frac{\text{endogenous mineral bound} - \text{gastric mineral bound}}{\text{endogenous mineral bound}} \times 100\%.
\]

\[
\% \text{ Bound } = \frac{\text{small intestine mineral bound} - \text{gastric mineral bound}}{\text{total exogenous mineral added (10,000 µg)}} \times 100\%.
\]

\[
\% \text{ released } = \frac{\text{small intestine mineral bound} - \text{colonic mineral bound}}{\text{small intestine mineral bound}} \times 100\%.
\]

2.6. Statistical Analysis

Each test was carried out in duplicate and all data were checked for normality with the Kolmogorov-Smirnov test. Experimental data were analysed by one way-ANOVA, using the GLM procedure of the SAS software [21].

3. RESULTS

3.1. Proximate Composition of Fibre Sources

The proximate compositions (moisture, ash, crude protein, and carbohydrate) of fibre sources are presented in Table 1. Moisture contents ranged from 6.25 to 9.05%. The
ash contents of tested fibre sources ranged from 0.53 to 2.09%. Except for pectin (3.16%), the crude protein contents of other fibre sources were low (0.01–0.38%). The calculated carbohydrates were in the range of 88.34–93.57%.

3.2. Viscosity and pH of Fibre Sources
The viscosities of carboxymethyl cellulose and pectin are substantially higher than those of other fibre sources. All other fibre sources have closely similar viscosities. The determined pH values indicate that pectin and Arbocel were acidic while the other fibre sources were slightly basic (Table 1).

3.3. In vitro Mineral-Binding Capacity of Fibre Sources
The endogenous contents of the five tested fibre sources are presented in Table 2. The mineral contents could fall into 2 categories: low (100–300) and very low (<2) levels. While there were very low levels of Fe (<2.13 µg), Cu (<0.10 µg), and Zn (<0.10 µg) per gram of fibre sources, the levels of Ca and Mg were reported to be low (<125 µg Ca/g and <300 µg Mg per gram of fibre sources).

The percentages of removed endogenous mineral contents of fibre sources in the simulated acidic conditions of the stomach are shown in Table 3. The results show that almost >90% of Ca and Mg, and >70% of Zn from all fibre sources were removed. However, the percentages of removed minerals varied widely for Fe (17.99–53.97%) and especially for Cu (26.97–83.80%) with regard to other.

The MBC of fibre sources under simulated conditions of the small intestine are summarised in Table 4. The mineral-binding ranges of the gastric-condition-treated fibre sources were low for Fe (0.97–7.01), Cu (2.54–9.23), and Zn (1.94–10.09), and relatively low for Mg (14.63–25.76). However, the binding capacity of fibre sources to Ca was remarkably high (37.75–47.00%).

Table 5 shows the percentage of released minerals in the simulated conditions of the colon. The findings showed that the release percentage ranges for Fe, Cu, Zn, Mg, and Ca were 4.07–88.70%, 23.57–80.80%, 75.00–97.91%, 23.28–50.26%, and 10.62–51.02%, respectively.

4. DISCUSSION

4.1. Proximate Analysis
The calculated range of 88.34–93.57% carbohydrates indicates that all tested fibre sources belong to fibre-rich foods (Table 1). Differences in moisture contents may be due to processing or storage conditions [15]. The processing conditions might have some effects on the results of this study. Moreover, the narrow range (6.25–9.05%) in moisture contents suggests little difference in terms of water-fibre interactions. The calculated moisture content is <10%, which agrees with the results of other studies on various fibre sources [11, 15]. The protein content was used as a measure of fibre purity. In general, all fibre sources except pectin showed a good index of purity.
The high concentration of crude protein in pectin (6.4%) has been reported in another study [7], which is consistent with this finding. This can result from either contamination, or may be associated with some fibre chains via covalent links. The measured crude protein for cellulose was close to zero (0.02), which is a result consistent with those of other studies [23, 26]. The ash contents are low (0.53–2.09%). This is comparable to the range (1.09–2.78) reported by Wong et al. [28], but is inconsistent with Hassani [11]. Generally, comparing different studies is difficult because systematic data on the ash composition of fibre sources are limited.

4.2. Viscosity and pH
The difference in solution pH influences fibre solubility. This difference in fibre solubility could affect other chemical properties of the fibre sources (e.g. viscosity) and influence their ability to react with minerals. Little information is available about the factors associated with the pH of fibre suspensions to allow useful comparisons. Concerning the measured pectin pH, only the result from Debon and Tester [7] was available (3.6), which is comparable to our result (3.14). The viscosities of pectin and carboxymethyl cellulose suspensions were substantially higher than those of other fibre sources. The viscosity of fibre source suspensions depends on the solubility, molecular weight, and structural chemical bonds of the fibre sources [5]. Other factors that possibly affect viscosity are the molecular size, spatial shape, and concentration of the fibre sources. The solubility, molecular weight, spatial shape, and structural linkages may have caused the differences in fibre viscosity in this study. In fact, the spatial structure of carboxymethyl cellulose and pectin dictates the water absorption and gel formation characteristics of these fibre sources and can cause increased viscosity of the prepared suspensions.

4.3. In vitro Mineral-Binding Capacity
The levels of endogenous minerals in the five purified fibre sources were remarkably lower than those of fibre sources prepared from different sources such as cereals, fruits, legumes, or vegetables [9, 13, 22]; commercial fibre supplements [17]; isolated fibre sources [6]; and various bran [15]. Therefore, they likely are not good dietary sources of these five minerals. On the other hand, the very low levels of Fe (<2.13 µg), Cu (<0.10 µg), and Zn (<0.10 µg), and the low levels of Ca (<125 µg) and Mg (<300 µg) per gram of fibre sources (Table 2) indicate that the purified fibre sources might have initially consisted of very small amounts of these minerals, or that considerable mineral reduction occurred during the fibre production process. For pectin, endogenous values of 56, 70, 4, 157, and 180 µg/g were reported for Mg, Fe, Zn, Ca, and Cu, respectively [25]. The reported values for Mg and Ca agree with this study, but other reported amounts are much higher than our results. This inconsistency is possibly related to the role of Mg and Ca in the cell wall structure. Despite the differences in their origin or processing method, fibre sources can maintain the original mineral levels in their structure. The very limited information
about the endogenous mineral contents of the tested fibre sources makes arriving at a comprehensive conclusion on this issue difficult.

Most of the endogenous Ca and Mg (almost >90%) and Zn (almost >70%) from all fibre sources were removed (Table 3). This suggests that upon reaching the stomach, most of the above-mentioned minerals would be readily released from the fibre sources. A similar phenomenon concerning fibre sources prepared from cereals, legumes, and fruit had been reported previously [6, 14, 16]. The more efficient removal of the endogenous Ca and Mg might be due to their weaker bonding energy, being less tightly bound to the interstices of the fibre structure [6, 16]. However, the pH [16] and the binding mechanism for Ca and Mg [26] are very important in this regard. Laszlo [16], and Thompson and Weber [26] noted that the ineffective release of endogenous Fe, Cu, and Zn under gastric conditions might suggest that the binding mechanism of these minerals might only be partially due to electrostatic interactions. Under an acidic pH, the most cationic functional groups of the fibre sources are believed to act as cation exchangers, which are responsible for the release of the minerals bound by fibre sources [17]. Besides, in environments with a high concentration of hydrogen ions, functional groups completely charged by hydrogen ions (-COOH, -SO\(_3\)H) are not desirable for the ionisation of the exposed cationic functional groups. Accordingly, this will cause a very weak electrostatic interaction with the divalent cations [7, 24]. Subsequently, only those sites on the fibre that are densely charged or are sterically accessible to the cations might maintain some minerals by absorption [24]. Our results on the amount of removed Zn from fibre sources are in disagreement with those of Laszlo [16] but agree with those of Idouraine et al. [13]. This phenomenon could possibly be due to the endogenous Zn contents of tested fibre sources, the created electrochemical conditions [16], or the accessibility of Zn [13].

Generally, the percentages of binding of the gastric-condition-treated fibre sources to Fe, Cu, Zn, and Mg under the simulated physiological conditions of the small intestine (Table 4) were low; however, the percentages of binding to Ca were remarkable, with the highest being that of carboxymethyl cellulose. The low binding to Fe, Cu, Zn, and Mg suggests that partially demineralised fibre sources from the stomach could only re-bind a limited amount of the five minerals in the small intestine and might have no detrimental effects on mineral bioavailability as compared with other fibre sources [10, 20]. The MBC of the fibre sources is dependent on their structural properties. If the major constituents of fibre sources are water-insoluble polysaccharides [29] or if they have relatively stable hydroxyl groups, then they might possess a low MBC [24]. The higher percentage of binding to Ca of fibre sources could imply 2 things: (1) there are a higher number of specific binding sites for Ca or (2) the number of binding sites is the same for all fibre sources, but they have a stronger affinity for Ca than for other minerals, as proposed by Idouraine et al. [14]. The extent of binding is directly related to the carboxyl group
contents [18], as ionisation of the carboxyl groups of free uronic acids is significantly correlated to Ca binding by fibre sources [3]. Thus, higher Ca binding could possibly be due to this phenomenon, which is in agreement with Debon and Tester [7]. The mineral-releasing capacity of the small-intestine-condition-treated fibre sources under the simulated physiological conditions of the colon was remarkably high (75–95%) for bound Zn (Table 5). This finding is matched by that of Idouraine et al. [13]. The low minerals-releasing capacity implied an electrostatic interaction. Except for carboxymethyl cellulose, it appears that as compared with Fe, Mg, Ca, and Cu, the binding of Zn to treated fibre sources is expected to be weaker [26]. This finding also implies a potential physiological benefit of these fibre sources concerning Zn bioavailability upon reaching the colon. Parts of the fibre sources would be fermented in the colon by the anaerobic microflora, thus releasing some of their bound Zn. This function would not only release appreciable amounts of bound Zn from fibre sources but might also promote the release of passed and unabsorbed Zn. This is expected for all tested minerals associated with pectin and carboxymethyl cellulose, with high fermentation ability. The additional absorption of Zn in the colon is very important for conditions where monogastric diets do not allow sufficient Zn intake or when there is insufficient active Zn absorption in the small intestine.

5. CONCLUSION

In general, all fibre sources tested in this study exhibited very low levels of Fe, Cu, and Zn, as well as low levels of Ca and Mg, and thus would not likely be good dietary sources of these five minerals. The percentages of binding of the gastric-condition-treated fibre sources to minerals (except for Ca) were low and might not have detrimental effects on mineral bioavailability. However, binding capacity should be considered along with GIT physiological conditions (pH, ionic strength, bacterial populations, and the presence of other minerals) and diets, which have interactions with minerals. The mineral-releasing capacity of fibre sources for Zn, and somewhat to Cu, was notable, and reabsorption of Zn and Cu can be considerable under the colon conditions. Finally, in vitro experiments can be beneficial for understanding the behaviour of fibre sources and minerals but should not take account quite similar to in vivo systems.

REFERENCES

In vitro mineral-binding capacity of various fibre sources 243

Table 1
Properties (proximate composition, pH and viscosity) of fiber sources

<table>
<thead>
<tr>
<th></th>
<th>Moisture (g/100g)</th>
<th>Ash (g/100g)</th>
<th>Protein (g/100g)</th>
<th>Calculated carbohydrates (^a) (g/100g)</th>
<th>pH (^b)</th>
<th>Viscosity (^c) (cP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pectin</td>
<td>8.5±0.28</td>
<td>1.09±0.00</td>
<td>3.16±0.01</td>
<td>88.34±0.30</td>
<td>3.14±0.03</td>
<td>6.14±1.14</td>
</tr>
<tr>
<td>CMC (^d)</td>
<td>8.20±0.14</td>
<td>2.09±0.11</td>
<td>0.01±0.00</td>
<td>91.69±0.00</td>
<td>7.49±0.69</td>
<td>11.8±0.79</td>
</tr>
<tr>
<td>Arbocel</td>
<td>9.05±0.07</td>
<td>0.53±0.04</td>
<td>0.38±0.01</td>
<td>90.57±0.08</td>
<td>4.62±0.31</td>
<td>2.46±0.16</td>
</tr>
<tr>
<td>Vitacel</td>
<td>6.25±0.07</td>
<td>1.10±0.05</td>
<td>0.05±0.00</td>
<td>93.70±0.07</td>
<td>7.72±0.03</td>
<td>1.79±0.13</td>
</tr>
<tr>
<td>Cellulose</td>
<td>7.15±0.07</td>
<td>1.10±0.03</td>
<td>0.02±0.00</td>
<td>92.88±0.00</td>
<td>7.81±0.01</td>
<td>2.11±0.01</td>
</tr>
</tbody>
</table>

SEM 0.076 0.031 0.004 0.091 0.170 0.313

P value  <0.001 <0.001 <0.001 0.004 <0.001 <0.001

\(^a\) Calculated= 100 – (moisture + ash + protein). \(^b\) pH of 0.1 % (w/v) solution at 25°C. 
\(^c\) Viscosity 0.1 % (w/v) solution at 25°C. \(^d\) Carboxymethyl cellulose.
### Table 2
The endogenous (µg/g) contents of fiber sources

<table>
<thead>
<tr>
<th></th>
<th>Fe</th>
<th>Mg</th>
<th>Ca</th>
<th>Cu</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pectin</td>
<td>1.47±0.01</td>
<td>94.08±0.36</td>
<td>156.75±0.71</td>
<td>0.04±0.00</td>
<td>0.11±0.00</td>
</tr>
<tr>
<td>CMC&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.14±0.00</td>
<td>232.11±3.21</td>
<td>157.45±1.70</td>
<td>0.07±0.00</td>
<td>0.05±0.00</td>
</tr>
<tr>
<td>Arbocel</td>
<td>2.13±0.01</td>
<td>175.12±4.59</td>
<td>109.18±0.28</td>
<td>0.09±0.00</td>
<td>0.05±0.00</td>
</tr>
<tr>
<td>Vitacel</td>
<td>2.00±0.00</td>
<td>187.04±0.65</td>
<td>124.24±1.40</td>
<td>0.06±0.00</td>
<td>0.05±0.00</td>
</tr>
<tr>
<td>Cellulose</td>
<td>0.98±0.01</td>
<td>293.19±5.21</td>
<td>123.68±1.87</td>
<td>0.07±0.00</td>
<td>0.05±0.00</td>
</tr>
<tr>
<td>SEM</td>
<td>0.004</td>
<td>1.718</td>
<td>0.666</td>
<td>0.022</td>
<td>0.001</td>
</tr>
<tr>
<td>P value</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

<sup>a</sup>- Data are average of two determinations values. <sup>b</sup>- Carboxymethyl cellulose.
**In vitro mineral-binding capacity of various fibre sources**

Table 3
The % removed a mineral in stimulated condition of stomach b

<table>
<thead>
<tr>
<th></th>
<th>Fe</th>
<th>Mg</th>
<th>Ca</th>
<th>Cu</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pectin</td>
<td>36.05±0.61</td>
<td>96.23±0.12</td>
<td>89.93±0.46</td>
<td>44.80±0.50</td>
<td>90.77±1.09</td>
</tr>
<tr>
<td>CMCc</td>
<td>17.99±0.62</td>
<td>98.31±0.24</td>
<td>90.58±0.96</td>
<td>72.62±0.64</td>
<td>77.57±0.60</td>
</tr>
<tr>
<td>Arbocel</td>
<td>41.65±0.06</td>
<td>96.42±0.09</td>
<td>86.92±0.90</td>
<td>83.24±1.25</td>
<td>73.99±0.01</td>
</tr>
<tr>
<td>Vitacel</td>
<td>31.82±0.48</td>
<td>90.63±0.89</td>
<td>88.89±0.52</td>
<td>39.63±0.70</td>
<td>79.96±0.23</td>
</tr>
<tr>
<td>Cellulose</td>
<td>53.97±0.34</td>
<td>90.87±0.49</td>
<td>89.81±0.44</td>
<td>26.9±0.26</td>
<td>73.86±0.37</td>
</tr>
<tr>
<td>SEM</td>
<td>0.235</td>
<td>0.235</td>
<td>0.347</td>
<td>0.374</td>
<td>0.295</td>
</tr>
<tr>
<td>P value</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.019</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

a- % removal = (endogenous mineral bound - gastric mineral bound) × 100/endogenous mineral bound. b- Data are average of two determinations values. c- Carboxymethyl cellulose.
Table 4
The *in vitro* mineral binding capacity of fiber sources under stimulated condition of small intestine

<table>
<thead>
<tr>
<th></th>
<th>Fe</th>
<th>Mg</th>
<th>Ca</th>
<th>Cu</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pectin</td>
<td>0.97±0.02</td>
<td>19.91±0.14</td>
<td>38.03±0.60</td>
<td>9.23±0.90</td>
<td>5.29±0.08</td>
</tr>
<tr>
<td>CMCcí</td>
<td>4.08±0.05</td>
<td>25.06±0.65</td>
<td>40.76±0.71</td>
<td>6.62±0.05</td>
<td>10.09±0.20</td>
</tr>
<tr>
<td>Arbocel</td>
<td>1.10±0.02</td>
<td>25.76±0.36</td>
<td>41.15±1.56</td>
<td>2.54±0.49</td>
<td>1.94±0.07</td>
</tr>
<tr>
<td>Vitacel</td>
<td>7.01±0.01</td>
<td>17.91±0.14</td>
<td>37.75±1.19</td>
<td>8.38±0.33</td>
<td>3.82±0.28</td>
</tr>
<tr>
<td>Cellulose</td>
<td>5.32±0.04</td>
<td>14.63±0.08</td>
<td>47.00±1.07</td>
<td>8.80±0.21</td>
<td>2.20±0.21</td>
</tr>
<tr>
<td>SEM</td>
<td>0.016</td>
<td>0.173</td>
<td>0.541</td>
<td>0.245</td>
<td>0.091</td>
</tr>
<tr>
<td>P value</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.002</td>
<td>0.002</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

a- % binding = (small intestinal mineral bound - gastric mineral bound) ×100/total exogenous mineral added (10000 µg).
b- Data are average of two determinations values. c- Carboxymethyl cellulose.
In vitro mineral-binding capacity of various fibre sources

Table 5
The releasing \(^a\) contents of minerals under stimulated condition of colon \(^b\)

<table>
<thead>
<tr>
<th></th>
<th>Fe</th>
<th>Mg</th>
<th>Ca</th>
<th>Cu</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pectin</td>
<td>15.82±0.75</td>
<td>50.26±0.15</td>
<td>48.98±1.02</td>
<td>69.92±0.33</td>
<td>94.71±0.32</td>
</tr>
<tr>
<td>CMC(^c)</td>
<td>4.07±0.08</td>
<td>49.65±0.78</td>
<td>41.99±1.02</td>
<td>64.46±1.62</td>
<td>97.91±0.86</td>
</tr>
<tr>
<td>Arbocel</td>
<td>12.88±0.15</td>
<td>45.64±0.72</td>
<td>15.82±1.03</td>
<td>23.57±0.47</td>
<td>75.00±0.92</td>
</tr>
<tr>
<td>Vitacel</td>
<td>88.70±0.36</td>
<td>30.04±0.16</td>
<td>51.02±0.31</td>
<td>80.80±0.63</td>
<td>80.02±0.17</td>
</tr>
<tr>
<td>Cellulose</td>
<td>42.86±0.49</td>
<td>23.28±0.38</td>
<td>10.62±0.87</td>
<td>30.02±0.27</td>
<td>91.03±0.30</td>
</tr>
<tr>
<td>SEM</td>
<td>0.219</td>
<td>0.242</td>
<td>0.447</td>
<td>0.413</td>
<td>0.325</td>
</tr>
<tr>
<td>P value</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

\(^a\) % releasing = (small intestinal mineral bound – colonic mineral bound) ×100/small intestinal mineral bound. \(^b\) Data are average of two determinations values. \(^c\) Carboxymethyl cellulose.

Received: May 5, 2012