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## STRUCTURE OF PHYTIC ACID AND PHYTATES

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The structure of phytic acid and of cobalt and iron phytates and pharmacopoeial phytin have been studied by diffuse reflection electron spectroscopy and IR spectroscopy. It has been shown that in the structure of the phytates, in contrast to that of phytic acid, there is a pyrophosphate bond formed as the result of the substitution of a proton in the  $\text{PO}_2(\text{OH})_2$  group by the metal ion.

Phytic acid is the hexaphosphoric ester of the hexahydric cyclic alcohol meso-inositol. Its salts with the alkaline-earth and alkaline metals form the basis of the research of phosphorus compounds in higher plants [1]. The mixed neutral calcium-magnesium salt of phytic acid is used in medical practice under the name of phytin in various diseases of the nervous system, vascular hypotonia, hysteria, neurasthenia, sexual impotence, malnutrition, rickets, anemia, tuberculosis, diatheses, and other conditions [2].

The structures of phytic acid and its salts have been widely studied [3-7], but even at the present time many questions of constitution and structure remain under discussion, which complicates the development of methods for monitoring the quality of the finished product and standardizing industrial forms of raw material.

We have studied the composition and structure of phytic acid and of an industrial sample of phytin and also of phytin obtained from various types of raw material. We have also studied calcium, iron, and cobalt phytates obtained from phytin and from pure phytic acid.

The state of the complex-forming ions and the structure of the compounds formed have been investigated by the methods of diffuse reflection electron spectroscopy and IR spectroscopy.

In the IR spectrum of phytic acid (Fig. 1a) strong absorption bands are observed with maxima at 1060 and 1400  $\text{cm}^{-1}$  which we have assigned to  $\nu(\text{P}-\text{O}-\text{C})$  and  $\nu(\text{P}=\text{O})$ , respectively. A weak absorption band obviously due to the  $\delta(\text{P}-\text{OH})$  vibrations appears at 1020  $\text{cm}^{-1}$ , and a band of medium intensity, due, in all probability, to a planar  $\delta(\text{P}-\text{OH})$  not involved in a H-bond [8], at 1218  $\text{cm}^{-1}$ , while a band at 1630  $\text{cm}^{-1}$  can be assigned to  $\delta(\text{O}-\text{H})$  from water molecules of hydration. At the same time, no  $\nu(\text{P}-\text{O}-\text{P})$  band was detected in phytic acid.

In contrast to phytic acid, in the spectrum of an industrial sample of phytin (Fig. 1b), a strong absorption band is observed at 980  $\text{cm}^{-1}$ , which is characteristic for the stretching vibrations of a pyrophosphate bond [9]. In addition, at 460  $\text{cm}^{-1}$ , there is a band of medium intensity due, in all probability, to the Me-O bond and absent, as was to be expected, from the spectrum of phytic acid. It is obvious that the formation of a

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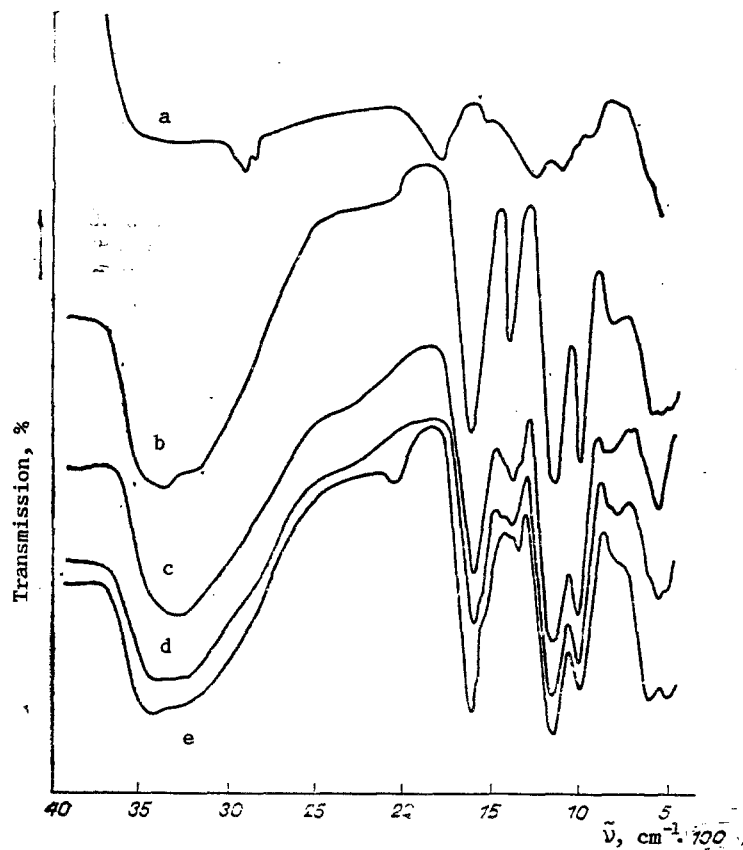


Fig. 1. IR spectra: a) phytic acid; b) industrial phytin; c) cobalt phytate; d) phytin from unroasted rice bran; e) phytin from the castor oil plant.

P-O-P bond leads to a high-frequency shift relative to phytic acid of the  $\nu(\text{P-O-C})$  absorption band by  $50 \text{ cm}^{-1}$ , while  $\nu(\text{P=O})$  shifts in the low-frequency direction by  $20 \text{ cm}^{-1}$ . Furthermore, the  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  ions present in phytin apparently exert a considerable influence on the shifts of  $\nu(\text{P-O-C})$  and  $\nu(\text{P=O})$ . The position of the maximum of the  $\nu(\text{P-O-C})$  absorption also depends on the nature of the metal ion present in the complex. For example, when  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  are replaced by  $\text{Co}^{2+}$  ions (Fig. 1c), or by iron(II) and (III) a low-frequency shift of the maximum of the  $\nu(\text{P-O-C})$  absorption by  $40\text{-}10 \text{ cm}^{-1}$  is observed.

Moreover, with the passage from phytic acid to phytates a low-frequency shift ( $55\text{-}20 \text{ cm}^{-1}$ ) in the  $\nu(\text{P=O})$  maximum is observed, which is a consequence of the presence of a bond of the  $\text{P=O} \rightarrow \text{Me}$  type. It is interesting to note that the replacement of a proton in the

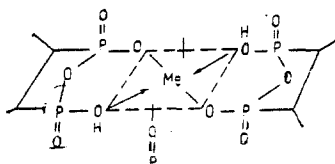
$$\begin{array}{c} \text{O} \\ \parallel \\ \text{P-O-Me} \end{array}$$

$\text{PO}(\text{OH})_2$  group by a metal ion leads to the appearance of an absorption band from  $\nu(\text{P-O-P})$  which is absent from the spectrum of phytic acid. A comparison of the spectra of an industrial sample of phytin and of the phytin obtained from various types of raw material - in particular, from unroasted rice bran and from the castor oil plant - and of cobalt and iron phytates shows the influence of the nature of the complex-forming ion and the type of raw material on the position of the absorption maximum due to  $\nu(\text{P-O-P})$ . The latter is explained by the fact that, depending on the type of raw material and the technology of obtaining the phytin, the composition and ratio of the mineral components will be different.

In the high-frequency region of the IR spectrum of phytic acid (Fig. 1a) two absorption bands are observed with maxima at  $2905$  and  $2840 \text{ cm}^{-1}$ , which we have assigned to  $\nu(\text{P-OH})$ . The high-frequency component of this band may be due to the vibrations of a free P-OH group, while the low-frequency component can, in all probability, be assigned to the P=O group. As was to be expected, the formation of the P-O-Me valence bonds in  $\text{Ca}^{2+}$ ,  $\text{Co}^{2+}$ , and  $\text{Fe}^{2+,3+}$  phytates leads to the disappearance in their spectra of the above-mentioned band due to the  $\nu(\text{P-OH})$  vibrations in the spectra of phytic acid.

On the basis of a comparative analysis of the vibrational spectra of phytic acid and phytates it is possible to assert the presence of the structure of an inorganic polymer with

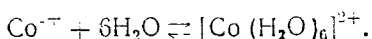
the realization of a six-membered chelate structure. For one fragment, obviously, the following scheme of the structure of the inner sphere will be valid:



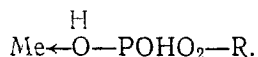
The diffuse reflection electronic spectra of hydrated cobalt phytate contains absorption bands from the  ${}^4A_{1g}({}^4F) \rightarrow {}^4T_{2g}({}^4F)$  ( $\nu_1$ ),  ${}^4T_{1g}({}^4F) \rightarrow {}^4A_{2g}({}^4F)$  ( $\nu_2$ ) and  ${}^4T_{1g}({}^4F) \rightarrow {}^4T_{1g}({}^4P)$  ( $\nu_3$ ) electronic transitions with maxima at 7500, 16,200, and 19,000  $\text{cm}^{-1}$ , respectively, showing a distorted Oh symmetry. Drying this sample at a temperature of the order of 105°C for 3 h led to a shift of the  $\nu_3$  and  $\nu_1$  absorption bands into the low-frequency region relative to the hydrated complex. The observed changes in the maxima of the electronic transitions are, in all probability, due to the replacement of a water molecule in the inner sphere by another functional group (for example,  $-\text{P}=\text{O}$ ), leading to larger values of the covalence of the Me-ligand bonds [10]. In favor of this hypothesis it is possible to give differences in the calculated values of the parameters of the crystal field for the two complexes:

Co(II) phytate	Electronic transitions			$D_g$ , $\text{cm}^{-1}$	$B$ , $\text{cm}^{-1}$	$\beta$
	$T_{1g}({}^4F) \rightarrow$					
	$\rightarrow T_{2g}({}^4F)$	$\rightarrow A_{2g}({}^4F)$	$\rightarrow T_{1g}({}^4P)$			
Hydrated	7500	16200	19000	870	400	0.39
Heat-treated	7400	17000	18800	960	733	0.71

The formation of pyrophosphate bonds on the passage from phytic acid to phytates can, in all probability, be explained from the aspects of the trans influence, the appearance of which is, in our opinion, a consequence of complex-formation, which is an involved and multistage process. It is known that  $\text{H}_2\text{O}$  possesses a low trans activity [11]. Furthermore, metal ions, including the ion of the 3d elements, form hydrated ions - aqua complexes - in solution [12]. In view of the substantial difference in the values of their electronegativities and electron affinities, the occurrence of the following stepwise processes may be assumed:



Because of the low trans activity of  $\text{H}_2\text{O}$ , we can assume its displacement from the trans position in the aqua complex by  $(\text{HO})_2\text{PO}_2-\text{R}-$  fragment with the formation of a



bond. The formation of this bond must lead to the appearance of a charge on the oxygen atom and, as a consequence, to the compensatory redistribution of the electron density in the  $(\text{OH})_2\text{PO}_2-\text{R}$  fragment. Consequently, complex-formation promotes a closer approach of the sterically hindered  $(\text{OH})_2\text{PO}_2-\text{R}$  group of phytic acid.

The discussion given above on the trans influence on complex-formation in compounds with phosphorus-containing ligands is in harmony with Troitskaya's results [13].

#### EXPERIMENTAL

Spectra of the samples in the UV and visible regions were recorded on a Specord M40 spectrophotometer. IR spectra were taken on a Specord 75 IR instrument in the frequency interval of 4000-500  $\text{cm}^{-1}$  in tablets with KBr.

#### SUMMARY

The results obtained permit us to assert the presence of differences in the structures of phytic acid and phytates. In contrast to phytic acid, phytates have a pyrophosphate bond which is formed as the result of the replacement of a proton in a  $\text{PO}_2(\text{OH})_2$  group by an ion of the metal complex-forming agent.

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#### ANALYSIS AND PREDICTION OF PRIMARY STRUCTURES OF PROTEINS USING A COMPUTER

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On the basis of a computer analysis of four classes of toxic polypeptides, generalized primary structures of each class have been obtained which can be used for planning the synthesis of biologically active compounds.

The increase in the number of deciphered amino acids and nucleotide sequences has made it necessary to create special automated systems for their storage, search, and processing. Banks of nucleotide sequences have been created in the USA (Los Alamos Bank, the Dayhoff Bank in Washington), the FRG (Heidelberg Bank of EMBL, GenBank, the PIR Protein Data Base (NBRF)), and other countries. Here in Moscow we have created the All-Union Bank of Nucleotide Sequences. Data bases exist in IMG AN SSSR, [Institute of Molecular Genetics of the USSR Academy of Sciences], IMB AN SSSR [Institute of Molecular Biology of the USSR Academy of Sciences], NIVTs AN SSSR [Scientific-Research Computer Center of the USSR Academy of Sciences], and VINITI [All-Union Institute of Scientific and Technical Information] and the formation is taking place of a data bank on molecular biology of ITsiG SO AN SSSR [Institute of Cytology and Genetics, Siberian Division of the USSR Academy of Sciences]; other banks are also being created. A basis for the spatial structures of biological macromolecules already exists - the National Protein Data Bank, containing the atomic coordinates of about 220 proteins. Here the rate of accumulation of information is 10-20 proteins per year, which is considerably lower than the rate of acquisition of information on primary structures [1-5].

Together with these "accumulators" of data, bibliographic information exists on publications in the field of molecular biology and genetics which contains thousands of names of sequences. They all solve problems of the collection and processing of published sequences, the input, editing, and storage of the corresponding information, and the systematization and search for required sequences. However, in some cases possibilities are being considered of the prediction of the chemical structures of proteins from the aspect of a definite function. In connection with this, the question of the generation of structures with predetermined properties requires special consideration.

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