Applications of Phytic Acid

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ABSTRACT

Phytic acid (myo-inositol hexaphosphate) constitutes 1-3% of most plant seeds. Its tremendous chelating potential and its effects on the absorption of polycationic nutrilites such as Ca^{2+}, Zn^{2+} and Fe^{3+} have been the subject of intense investigation for several decades. Yet in the American literature there is virtually no information available on other chemical properties of phytic acid or on its beneficial utilization. This review summarizes the present medical, dental, nutritional and industrial applications of phytic acid and suggests additional novel uses for this inexpensive and easily obtained chemical.

INTRODUCTION

Phytic acid is a major component of all plant seeds, constituting 1-3% by weight of many cereals and oilseeds (Table I) and typically accounting for 60-90% of the total phosphorus. It usually occurs as a mixed calcium-magnesium-potassium salt (phytin) in discrete regions of the seeds, such as the aleurone layer of wheat and rice (6), in the germ of corn (7), and in crystalloid-type globoids of many oilseeds (8). Phytic acid may serve several important physiological functions during dormancy and germination. These include the storage of phosphorus (9), high-energy phosphoryl groups (10), cations (11) and a cell wall precursor (12). Furthermore, phytic acid is believed to protect seeds against oxidative damage during storage (13).

The unique structure of phytic acid (Fig. 1) suggests tremendous chelating potential. It precipitates Fe^{3+} quantitatively at low pH. This property forms the basis of most methods for the determination of phytic acid (15). At intermediate and high pH it forms insoluble complexes with all other polyvalent cations (16-18) lowering the nutritional bioavailability of several trace minerals. This interference with intestinal absorption of cations may lead to mineral deficiencies in humans under certain circumstances. Nutritional implications of phytic acid have been discussed exhaustively in several authoritative reviews (3,19-24).

In addition to interacting with minerals, phytic acid precipitates most proteins at low pH in the absence of cations by binding to protonated basic residues and at high pH in the presence of cations, presumably by forming a ternary protein-metal-phytate complex (25). Some concern has been raised regarding its effect on protein availability in nutrition because low levels of phytic acid substantially inhibit the digestive enzyme trypsin (26). Phytic acid also binds to deoxygenated and oxygenated hemoglobin with dissociation constants of 6×10^{-8} M (27) and ca. 1×10^{-6} M (28), respectively. This interaction stabilizes the tetramer of methemoglobin (29) and displays a pronounced Bohr effect, i.e., it reduces the affinity of hemoglobin for O_2 or CO (30,31), and thus mimics the action of 2,3-diphosphoglycerate, the most common helcotropic agent.

Phytic acid also is a good antioxidant. Unlike most chelators, it forms a complex with Fe^{3+} that lacks iron-coordinated water and thus is unable to catalyze the formation of hydroxyl radicals in the Fenton reaction and Haber-Weiss cycle (32). It markedly inhibits the oxidation of ascorbic acid (vitamin C) (33), stabilizes sorbic acid (34), and prevents peroxidation and hydrolysis of fats and oils (35,36). Synergistic effects of mixtures of tocopherol (vitamin E) and phytic acid have also proven useful for the protection against autoxidation of methyl oleate and other lipids (37).

TABLE I

Phytic Acid Content of Selected Seeds

Sample	Phytic acid (% w/w)	Reference
Waldron wheat	1.1	1
Waldron wheat bran	4.8	2
Wheat germ	3.9	3
Corn	0.9	3
Corn bran	0	2
Corn germ	6.4	3
Soy beans	1.4	3
Soy flakes	1.8	4
Soy hulls	0.1	2
Dehulled sesame seeds	5.3	4
Peanuts	1.9	4
Dehydrated peas	0.9	4
Lima beans	2.5	5
Barley	1.0	5
Oats	0.8	5
Wild rice	2.2	5
Sunflower seeds	1.9	5

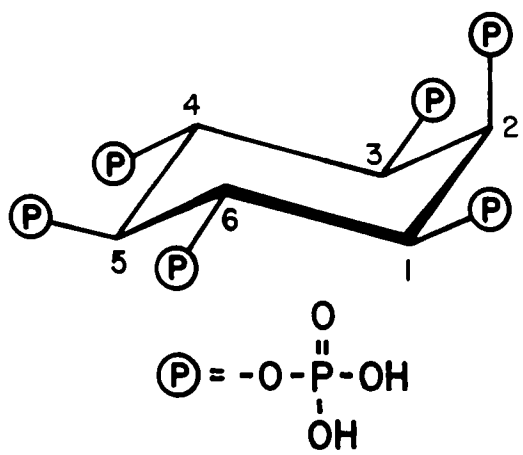

FIG. 1. Structure of phytic acid in dilute solution. This conformation was deduced by spectroscopic methods (14).

Most of the research on phytic acid in the United States over the past three decades has focused on its chelating properties and the resulting nutrilite deficiencies. In the American literature there is virtually no information available on other chemical properties of phytic acid or on the beneficial utilization of this unique compound. It is the intent of this review to summarize the present industrial applications of phytic acid, and to suggest additional novel uses for this inexpensive and easily obtained chemical.

PREPARATION OF PHYTIC ACID

Large amounts of phytic acid can be prepared in pure form at low cost from various plant sources (Table I). Most wheat brans contain between 4 and 5% phytic acid that can be extracted with dilute HCl at room temperature, precipitated by the addition of $FeCl_3$, bicarbonates, KOH, NaOH, NH_4OH, $Ca(OH)_2$, $Mg(OH)_2$ or alcohol, and further purified by standard chemical techniques.

There are several published methods for the preparation of phytic acid. Phytic acid was extracted from cereals, bran, glutens, plant embryos and seeds using aqueous H_2SO_4. It

was then precipitated with ammonia gas, and purified by ion-exchange chromatography on Amberlite IR-120 and Amberlite IR-45 (38). Similarly, phytic acid was produced from aqueous HCl extracts of rice bran and other wastes of the food industry, precipitated with $NaHCO_3$, and purified by extracting with ether from a 0.1 N HCl solution (39). In another procedure, the HCl extract of rice bran was decolorized, treated with $Ca(OH)_2$ and $Mg(OH)_2$, and the pH was raised from 3.4 to 7.0 with NaOH to give a phytin-like salt of phytic acid in high yield (40); 23 g of phytin were also obtained from 250 g of defatted rice bran by simply treating the decolorized HCl extract with ethanol and drying the precipitate (41). Ammonium chloride was employed for the isolation of phytin from cottonseed grist (42) and from the mother liquor of wastes following the production of edible proteins from cottonseed oil-cake (43). Aluminum phytate was prepared by adding $AlCl_3$ to aqueous H_2SO_4 extracts of defatted rice bran and adjusting the pH to 3.0-4.0 (44). Two examples of successful industrial production of phytic acid include the development of continuous extraction of phytin from cottonseed oil-cake with 0.57% HNO_3 (45) and the large-scale isolation of pure phytic acid from raw materials such as meal, rice bran and other byproducts of the food industry (46).

Most of the above preparations consist of phytin-like salts containing nonstoichiometric amounts of mono- and divalent cations. These phytins can easily be converted into a number of well defined salts, such as Na_{12}-phytate, $CaNaH_9$-phytate, Ca_2NaH_7-phytate, $MgKH_9$-phytate, $CaMgKH_7$-phytate, $Fe^{3+}H_9$-phytate, $Fe^{2+}{}_2H_8$-phytate, $Cu^{2+}H_{10}$-phytate, $Cu^{2+}Fe^{2+}H_8$-phytate, AgH_{11}-phytate and recrystallized from ethanol or methanol (47,48). Free phytic acid is prepared by passing phytin over a cation-exchange resin in the H^+-form. However, all crystallization attempts have been unsuccessful, which necessitates its storage as a concentrated solution, as one of the above salts, or as a starch powder prepared by spray-drying or vacuum-drying an aqueous mixture of phytic acid and dextrin (49, 50).

Commercially available phytic acid in the United States is prepared from corn and sold as a hydrated dodecasodium salt by Sigma Chemical Company. However, economically, it might be advantageous to extract waste products from the food or milling industry directly at the site of generation, and thus prepare large quantities of phytic acid at modest expense.

INDUSTRIAL APPLICATIONS

Uses in the Food Industry

Calcium phytate is, as yet, not affirmed as GRAS (generally recognized as safe) by the United States Food and Drug Administration because it claims there is no evidence that it is currently used in food manufacture (51). However, outside the United States phytic acid is being employed extensively as a food additive. Several of its characteristics have been summarized in two recent reviews (52,53).

The antioxidant or Fe^{3+}-chelating properties of phytic acid described above render this compound a unique and versatile food preservative. It prevents both autoxidation and hydrolysis of soybean oil (36,54) and stabilizes other lipid-containing foods against rancidity (55). Its addition to foods preserves meat (56), fish meal pastes (57), cooked noodles (58), bread, salad, fish (59), and stabilizes both natural and artificial coloring agents, e.g., it prevents discoloration of a riboflavin solution (60), of caviar (61), of fresh vegetables (62,63), and of dried sardine fingerling (64), improving the nutritional quality of these food items and prolonging their shelf-life. Also, the darkening on heating of processed foods containing eggs, such as egg custard, is prevented with 0.01% phytic acid or its salts (65).

Several other nutritional applications of the metal-chelating properties of phytic acid have been published. Treatment of liquids with phytate removed more than 99.5% of the iron from solutions, such as diluted molasses (66), wines (67) and other beverages (68). A similar treatment was employed to free foods and water from radioactive contaminants, such as ^{90}Sr (69). Among a large number of chelating agents investigated, phytic acid and its alkali metal salts were preferred as antiscum and antifoam additives in instant coffee (70). Its addition to canned asparagus retarded the release of tin from tin-plate cans into the food (71). Chelation of free Ca^{2+} and Mg^{2+} by phytic acid also leads to softening of cooked old potatoes (72) and of steamed soybeans used for miso manufacture (73) and it improves the cooking quality of peas by preventing the crosslinking of uronic acid groups of pectin (74,75).

In the presence of Ca^{2+} and Mg^{2+}, phytic acid coagulates soybean protein and allegedly improves the texture and flavor of tofu (76). Other miscellaneous applications to the industry include the use of phytic acid for the deodorization of garlic (77), for the preparation of an edible collagen sausage casing (78), for the preparation of a fibrous dairy product with high protein content (79) and as a food additive to shorten the reconstitution time of dried vegetable products, such as pastes, corn products, fruit and vegetables (80).

Nutritionists have only considered the deleterious aspects of phytic acid, even though only in rare instances has it been implicated as a direct cause of human trace mineral deficiencies. Cationic imbalances usually occurred in malnourished populations, e.g., Zn^{2+} deficiencies in some Iranian tribes (81,82) and in low-income preschool children in the United States (83). Caloric inadequacy of their diets may have potentiated the phytate impairment of mineral bioavailability and its clinical symptoms.

The ingestion of large doses of phytic acid elicited no physiological discomfort or symptoms of any toxicological action in humans (84). Furthermore, neither phytic acid nor any of its metabolites are toxic or highly reactive, which certainly renders it a more favorable food additive than numerous other preservatives currently on the market, e.g., nitrite and metabisulfite. Thus, in addition to performing research on methods for eliminating phytic acid from food, nutritionists will have to develop dietary regimens for subjects susceptible to mineral deficiencies that will obliterate the antinutritional effects of phytic acid through appropriate fortification with trace elements.

Medical Applications

Injectable ^{99m}Tc-labeled phytate colloids have gained widespread acceptance as imaging agents for organ scintigraphy. ^{99m}Tc-Sn-phytate was originally introduced as a hepatic scanning agent (85), but since then ^{99m}Tc-phytate colloids have been used successfully for the scintigraphy of the spleen (86-89), kidney (87,90), lungs (88,90,91), reticuloendothelial system (92,93) and lymph nodes (94). Several methods for the preparation of ^{99m}Tc-calcium-phytate and ^{99m}Tc-Sn-phytate have been reported (92,93,95-97).

Ten to 30 min after the intravenous administration of ^{99m}Tc-calcium-phytate or ^{99m}Tc-Sn-phytate, 60-90% of the total injected activity is accumulated by the liver and stored with a biological half-life of ca. 112 hr (98). Smaller amounts are transported to the kidneys, lungs, spleen, bone marrow and reticuloendothelial system. The exact organ distribution depends on both the aggregation state of the labeled colloid and the physiological condition of the patient, e.g., stimulating the reticuloendothelial system

with endotoxin or increasing the particle size of the colloid improved the uptake by the spleen and lungs (88).

Recently ^{113m}In-phytate was shown to be an alternative hepatic scanning agent (99). The pharmacological study indicated a selective uptake into the liver of 80% of the initial dose 15 min postadministration. Clinical investigations performed on 120 patients demonstrated the usefulness of this radiopharmaceutical for liver imaging. ^{169}Yb-phytate is another new scanning agent for functional scintigraphy of the liver, giving good visualization of space occupying lesions in patients with hepatomegaly (100).

Phytate colloids prove to be useful not only for organ scintigraphy, but also for improvement of the effectiveness of barium sulfate as an X-ray contrast agent (101). A typical contrast medium containing $BaSO_4$, phytin, CM-cellulose, sorbate, silicone and yogurt essence showed good adhesiveness to animal tissues and smooth flowing properties.

A multitude of various other medical applications have been described, some of which merit further investigation. Oral preparations of sodium and bismuth salts of phytic acid reduce gastric secretion and have been effective in treating gastritis, gastroduodenitis, gastroduodenal ulcers and diarrhea (102-104). Similar antiulcer activity has been displayed by salts of the sulfur analog of phytic acid, myo-inositol hexasulfate (105-108).

Calcium phytate has been employed as an oral antidote for lead poisoning in mice (109) and it may also have protective effects against toxic metal absorption in humans. The strong Ca^{2+}-chelating potential of phytic acid over a wide pH range (110) also forms the basis of its therapeutic use in prevention and dissolution of calcium deposits in subjects with various diseases (111), e.g., cases of chronic bronchopneumopathy and diseases of the vertebral column were successfully treated with phytate. Its oral administration was also useful in reducing the Ca^{2+} concentration in urine, thus checking the formation of renal calculi (112). This agrees with a recent epidemiological study that demonstrated an inverse correlation between the amount of phytic acid consumed and the incidence of renal stones (113). The same inverse correlation was observed between dietary phytate and ischemic heart disease, which may be the direct result of decreased plasma cholesterol levels, as a diet containing high phytate contents produced hypocholesterolemia in rats (114). The mechanism of this protective effect remains to be elucidated.

Phytic acid has been used as a preventive agent against severe poisoning with pressurized oxygen (115) and it was effective in preventing thirst during exercise, during labor and with diseases (116). Amino acid salts of phytate were claimed to have both antiasthenic and protein-anabolizing effects in rats (117). Finally, phytic acid salts of various antibiotics were prepared for therapeutic purposes (118, 119) and potassium phytate proved useful for the oral administration to warm-blooded animals of nonbitter tasting potassium, a product leaving no metallic aftertaste in humans (120).

This concise summary of medical applications demonstrates the potential usefulness of phytic acid and its derivatives in medicine. Many of the above preliminary results will require confirmation through further biochemical and clinical experimentation. At the same time, while optimizing and expanding therapeutic uses, concerted research efforts must be focused on assessing the physiological side-effects of long-term administration of phytic acid and its various salts.

Dental Applications

Several epidemiological studies have reported a significantly elevated incidence of dental caries concomitant with the change in dietary habits in Western societies (121). This increase has been hypothesized to be the result of decreased phytate consumption. This observation was substantiated by the increased cariogenicity of flour on refinement (122). Subsequently, several investigators provided unambiguous evidence for the cariostatic effects of dietary phytic acid in rats (123-126), hamsters (127) and monkeys (128).

The cariostatic effect of phytic acid has been ascribed to its ability to inhibit the dissolution of calcium phosphate and tooth enamel (122, 129-132). Phytic acid was adsorbed rapidly by hydroxyapatite from solutions as dilute as 10^{-6} M (133) which reduced the solubility of the resin in acid (134,135).

Based on these cariostatic properties several commercial oral care compositions containing phytic acid have been formulated and patented, including dentifrices (136-144), mouth rinses (138,141,144), dental cements (145,146), cleaning agents for dentures (147) and an adhesive film for removing nicotine tar from teeth (148). A previous review discusses various results of the applications of phosphorylated polyol calcium salts to dental caries prevention (149).

A somewhat different application has been the addition of 1% phytic acid to dentifrice formulations incompatible with uncoated aluminum tubes to suppress the swelling and release of gas observed in the absence of phytic acid (150).

Despite these promising results, very few research efforts have been concentrated in the United States on the biochemical mode of action of phytic acid and its applications to oral care. Using a relatively small expenditure of R&D, a host of novel dental hygiene and health care products could be developed. Such investigations seem especially desirable due to the natural abundance of phytic acid, its nontoxicity, inertness and stability.

Corrosion Inhibition by Phytic Acid

The tremendous chelating potential of phytic acid confers excellent anticorrosive properties on the molecule and its salts. Extensive studies have demonstrated that phytate coating of metals and alloys imparts to them both corrosion inhibition and improved adhesion of organic finishes. Also there is general agreement that conventional surface treatment of steels with chromate is inferior to that with phytic acid.

On surface treatment with various salts of phytic acid, tin plates and cans showed good oxidation, corrosion and scratch resistance, good solderability, resistance toward blackening by sulfur and superior appearance (151-155). Phytate treatment imparted long-lasting corrosion protection and improved paint adhesion also to steel (156-159), galvanized steel (159-161), phosphate conversion-coated steel (159,162-165), iron (154,165,166), zinc or its alloys (165,167-172), copper (154,173) and aluminum or its alloys (174-183).

In addition to direct coating of these metals, the anticorrosive properties of phytic acid have found many other useful applications. Gypsum-based heat-insulating building material contained phytic acid to prevent the corrosion of the steel frames that it was poured into (184). Anticorrosive primers (185) and paint additives (186) containing phytic acid produced films of improved hardness, flexibility, adhesion and corrosion resistance. An active cleaner and rust remover useful for automobile radiators was formulated which contained phytic acid and was marked by high corrosion inhibition and solution stability (187). The addition of phytic acid to conventional lubricating greases significantly inhibited the corrosion of bearings (188,189).

The above results illustrate the desirable anticorrosive properties of phytic acid and some of their industrial

applications, and a thorough market analysis certainly will reveal many more advantageous uses of phytic acid as a corrosion-inhibiting agent.

Miscellaneous Applications

The multitude and diversity of the following applications prohibit their being discussed in depth and categorized into coherent entities. Therefore, they will simply be enumerated in a rather arbitrary sequence.

The high chelating potential of phytic acid has been utilized for the determination of Ce^{4+} in La_2O_3 by polarographic (190,191) or inverse voltammetric (192) analysis of Ce(IV) phytate. Phytic acid also is a useful and inexpensive precipitating agent for the extraction and separation of rare earth metals from ores (193).

Further applications of the high affinity of phytic acid for polyvalent cations include the preparation of various cleaning compositions, such as a cleaning solution for toilets to chelate the urinary calcium (194), a cleaning solution for removing oily and greasy contaminants from tinplates (195), a water additive to remove scale-forming components in boilers, cooling towers, evaporators, etc. (196), an agent for cleaning of polymerization reactors for polyester manufacture (197) and for preventing deposits on the inner wall surfaces of reactors used in the polymerization of olefins (198-200). Many of these resins are permanently heat- and light-stabilized by the incorporation of minute amounts of phytic acid (201,202).

Phytic acid was also added as an antistatic agent during the polymerization of ethylene to give polymers with good transparency (203). Similarly, immersion of solid, synthetic hydrophobic, nonconductive materials in an aqueous solution containing phytic acid produced fabrics with improved crease recovery (204) and with reduced tendency to generate and accumulate electric charges (205) and thus proved to be an efficacious fire retardant for cotton, polyester and silk textiles (206). When parchment paper impregnated with a number of different phytate salts was used for pressing out brass plates, the foil showed no oxide layer, further indicating the antistatic and antioxidant properties of phytic acid (207). The antistatic treatment of organic combustible substances with phytate salts significantly lowered their resistivity (208,209) and may be useful for diminishing explosion hazards of fuels; phytate salts have been employed successfully as aviation fuel additives to increase the electric conductivity (210,211).

Not only has phytic acid been used as a cation scavenger and catalyst for the polymerization of olefins, but it was also employed as a solvent (50-95% aqueous phytic acid) for the preparation of polyamide and polyurethane fibers of good tensile strength (212) and as a reagent for the synthesis of phosphorus-containing polyurethanes to give a nonburning foam (213).

Several lithographic desensitizing solutions containing phytic acid or its metal salts have been described (214-221). These solutions appear especially useful in preparing lithographic plates from ZnO-based electrophotographic plates. Such plates may yield >30,000 copies without blemishes when a wetting solution obtained by diluting the desensitizing solution was utilized (218). An entirely different application of phytic acid in lithographics is the preparation of presensitized positive working lithographic plates by applying a light-sensitive diazo compound to an aluminum lithographic base sheet and treating it with phytic acid to render the coating water-insoluble (222,223). After imagewise exposure, the unexposed diazo areas are coupled with pentanedione, the plates are washed, dried, lacquered and mounted on a lithographic printing press to yield at least 35,000 satisfactory impressions. Finally, the addition of phytic acid to photographic developers has been claimed to give fog- and stain-free color images (224), presumably by complexing free Ca^{2+} in tap water.

Phytic acid was employed as a coacervate-forming agent to prepare gelatin microcapsules containing heat-sensitive image recording materials (225). Similar microcapsules were used as coatings for pressure-sensitive copying paper and adhesives (226).

Oral administration of phytic acid was claimed to be effective in treating acne, improving skin color, blood circulation and fingernail growth (227). Additional cosmetic applications include the preparation of antidandruff hair lotions, rinses and shampoos (228) and of skin care lotions containing phytic acid which inhibits tyrosinase, an enzyme responsible for skin discoloration (229). More experimental data seems to be required, however, to support the validity of these cosmetic applications.

Phytic acid was used as a hardening accelerator for anaerobic resins (230,231). Filtering grids were prepared by pressing a mixture of cellulose, diatomite and phytin (232). Unilateral galvanization of steel strips was accomplished by temporarily coating the other side with aqueous 5% phytic acid/2% $AlPO_4$ (233). Glass plates were sprayed with a mixture containing phytic acid to form a strongly adherent coating which displayed good transparency and excellent fogging resistance (234). Wastewaters from meat-processing plants were treated with phytic acid to remove blood (235).

Phytic acid has been found to inhibit aflatoxin production by *Aspergillus parasiticus*, probably through chelation of zinc (236,237). Despite the agricultural importance of this discovery, it has received very little attention. Further investigations are required to elucidate the exact mechanism of the parasitic relationship between *Aspergillus parasiticus* and various seeds and of the inhibition of aflatoxin synthesis by phytate. A clear understanding of these processes might lead to important applications for the production of safer agricultural food and feed commodities.

Phytic acid not only suppresses the production of aflatoxin, but it also enhances the biosynthetic formation of some important pharmaceuticals. Its addition to a medium containing *Micromonospora sagamiensis* stimulated the fermentative production of gentamycins and aminoglycoside antibiotics severalfold (238). Significant promotion was also observed in the presence of activated sludges and rice bran, both of which are rich in phytin. The secretion of α-1,6-glucosidase and β-amylase into the culture medium by *Bacillus cereus mycoides* was raised by 0.1% calcium phytate from 615 to 1082 and from 18 to 1027 units/mL, respectively (239). Phytic acid was also used as a growth-promoting factor during the cultivation of yeasts for use in feeds (240). The yeast yield was 71.7 and 45.1% in its presence and absence. Finally, the addition of phytic acid to artificial silkworm feed markedly increased cocoon weight, cocoon silk layer weight and percentage of cocoon formation by the silkworm (241).

This compilation of industrial applications illustrates the broad scope of potential usefulness of phytic acid. Even though many of the above findings have not been confirmed or investigated thoroughly, they at least point out the many unique and desirable properties of phytic acid. It is hoped that many of these applications will be adopted as such, modified to suit changing needs, and also lead to new discoveries.

PROSPECTS AND SUGGESTIONS

In view of the abundance of phytic acid in plants, its ease of purification, and the multifarious applications, it is surprising that repeated discussions on the putative anti-

nutritional properties of phytic acid pervade the American literature, yet no mention is made of its potential usefulness.

Even though phytic acid precipitates polyvalent cations at intestinal pH, its presence in the diet has only in rare instances been directly linked to mineral deficiencies in humans, and its interference with the mineral bioavailability in animals is still controversial. Most recently it was found that at intestinal pH phytate forms a soluble complex with all polyvalent cations at high phytate to metal ratio (242); however, Fe_i-phytate administered to mice by gastric gavage was unavailable for absorption, in contrast with a previous report (243). Therefore, in conjunction with the development of nutritional applications of phytic acid, methods for neutralizing its antinutritional effects will have to be devised, such as appropriate mineral fortification. Considering the broad scope of usefulness of phytic acid and the safety status of several presently available commercial food additives, phytic acid as a versatile and useful chemical in the food industry certainly merits further investigation.

This review, I hope, will instigate not only the adoption and improvement of the above-cited applications, but also the development of novel uses of phytic acid in the various fields, including: (a) the addition of phytic acid to toxic or radioactive metal wastes in disposal barrels to limit their dissolution and contamination of the surroundings; (b) phytate treatment of sludges containing high levels of toxic metals; and (c) the detection of blood stains in forensics using radioactive phytic acid.

Another promising area of investigation will be the in vivo effects of phytic acid on hemoglobin. Recently, the irreversible incorporation of phytic acid into intact human erythrocytes was accomplished by ultrasonicating phytate-containing phospholipid vesicles with the red blood cells (244-247). The fusion of these vesicles with erythrocytes caused a decrease in O_2 half-saturation pressure and facilitated CO_2 transport in the capillary system. The modifications of the gas transport of phytate-loaded erythrocytes lasted over a significant period of time, which may prove to be of clinical usefulness in treating various disorders by transfusion.

Of broad nutritional and medical significance will be the preparation of myo-inositol mono-, di-, tri-, tetra- and pentaphosphate esters and the investigation of their interactions with different polyvalent cations. Conceivably, one or more of these compounds will form strong soluble complexes with metal ions, as suggested by the potent inhibition of mineralization (248) and of biological calcification of rat cartilage (249) by partial acid hydrolysates of phytic acid. Such a soluble chelator might be valuable for the treatment of systemic metal poisoning and possibly of hypercholesterolemia, for the dissolution of renal calculi and for the reduction of the iron overload in patients with idiopathic hemochromatosis, and it also might be a versatile food additive that would facilitate mineral absorption and still have many of the preservative properties discussed in the above nutritional applications.

An additional research area with far-reaching applicability in numerous disciplines will be the synthesis and characterization of various phytate-containing resins. Recently prepared XAD-phytate proved to be a powerful cation-exchanger (250) and its bacteriostatic effects are presently under investigation in our laboratory, since it is well documented that hyperferremia impairs the host's defense against microorganisms and enhances bacterial virulence (251). Thus, XAD-phytate applied to a wound-dressing might have therapeutic potential. Several other phytate-containing macromolecules with a high affinity for cations and hemoglobin will be clinically useful in a host of applications.

The present review, I hope, will stimulate many more research areas in the utilization of phytic acid, this ubiquitous and abundant plant constituent and waste product in the food and milling industry.

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Factors Affecting the Desolventization of Canola Meal

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ABSTRACT

Factors affecting the level of residual solvent in hexane-extracted canola meal included the moisture content of the crushed seed and the temperature of the hexane at the time of extraction, the duration of the extraction process and the severity of the cooking procedure prior to extraction. Low moisture, low temperature extraction, short exposure to excess hexane and mild cooking procedures all contribute to minimizing the levels of sorbed hexane after desolventization was complete. Dry heat could drive off only part of the residual hexane. Moist heat, as steam, was more effective.

INTRODUCTION

Oil recovery from canola seed, as performed by the oilseed crushing industry, almost invariably involves solvent extraction with commercial hexane. Inevitably, a small residue of solvent is retained by the meal after the desolventization process. It is desirable for several reasons to minimize the amount of residual solvent in the meal. Toxicological effects must be considered, especially if canola meal is to be utilized as a source of protein for human food (1-4). There has been insufficient testing to establish whether any health hazard is associated with the levels of residual hexane that occur typically in canola meal, but the possibility of such a hazard cannot be ignored. For a crushing plant to operate on a continuous basis, hexane must be added to make up for the amount which is not recovered from the meal. High make-up volumes contribute significantly to operating costs and escalating prices for hexane have magnified this problem. In some circumstances, high levels of residual hexane may create a potential fire and explosion hazard.

A laboratory study has been performed to investigate a number of factors which conceivably could affect the amount of residual hexane sorbed on canola meal. The factors chosen for testing have been related to controllable parameters in the operation of a crushing plant. These include moisture content of the seed, cooking time, cooking temperature, solvent temperature and both heat and moisture input in the operation of the desolventizer. The results of the study have suggested modifications in processing conditions which the industry could explore in order to minimize residual hexane in canola meal, without adversely affecting either product quality or operating efficiency.

EXPERIMENTAL PROCEDURE

Starting Materials

Starting materials included canola seed, reroll meal (material removed from the processing stream of a commercial plant

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