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ARTICLE

Low Phytic Acid Lentils (*Lens culinaris* L.): A Potential Solution for Increased Micronutrient Bioavailability

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Phytic acid is an antinutrient present mainly in seeds of grain crops such as legumes and cereals. It has the potential to bind mineral micronutrients in food and reduce their bioavailability. This study analyzed the phytic acid concentration in seeds of 19 lentil (*Lens culinaris* L.) genotypes grown at two locations for two years in Saskatchewan, Canada. The objectives of this study were to determine (1) the levels of phytic acid in commercial lentil genotypes and (2) the impact of postharvest processing and (3) the effect of boiling on the stability of phytic aid in selected lentil genotypes. The phytic acid was analyzed by high-performance anion exchange separation followed by conductivity detection. The Saskatchewan-grown lentils were naturally low in phytic acid (phytic acid = 2.5−4.4 mg g^{-1}; phytic acid phosphorus = 0.7−1.2 mg g^{-1}), with concentrations lower than those reported for low phytic acid mutants of corn, wheat, common bean, and soybean. Decortication prior to cooking further reduced total phytic acid by >50%. As lowering phytic acid intake can lead to increased mineral bioavailability, dietary inclusion of Canadian lentils may have significant benefits in regions with widespread micronutrient malnutrition.

KEYWORDS: Phytic acid; lentil; phytic acid phosphorus; bioavailability

INTRODUCTION

Phytic acid, or 1,2,3,4,5,6-hexakis (dihydrogen phosphate) *myo*-inositol, is present as salts of calcium (Ca), magnesium (Mg), or potassium (K) and as mixed salts in plants and soils. Inositol penta- (IP5), tetra- (IP4), and triphosphate (IP3) are also known as phytate. Phytic acid and its salts are ubiquitous compounds in plants, present at levels of 0.5−5% (w/w) in edible legumes, cereal grains, oilseeds, and nuts (*1*−*4*). Phytate is regarded as the principal storage form of phosphorus in many plant tissues, especially in bran and seeds (*3*). Phytic acid modifies the bioavailability of metal ions (e.g., Fe, Zn, and Cu), is an antioxidant, shows anticarcinogenic/ antineoplastic properties, reduces or prevents kidney stone formation, and plays important roles in many physiological processes (*5*).

The properties of phytic acid in mammalian biological systems are influenced by its behavior in solution (primarily aqueous solution and biological fluids), where it interacts with many metal and nonmetal ions, proteins, and starches. When consumed in feeds and foods, phytic acid binds to nutritionally important mineral cations such as Ca, Fe, and Zn in the intestinal tract, which can lead to micronutrient deficiencies (*6*). More than 90% of phytic acid is complexed with Na cations between pH 4 and 10. Phytic acid also has strong affinity to bind with other cations such as K, Cu, Co, Mg, and Ca (in decreasing order) (*2*). When chelated with Fe, phytic acid is an inhibitor of Fe-driven hydroxyl radical formation (*2*). $Fe(III)_4$−phytate complexes block hydroxyl radical formation and strongly suppress lipid peroxidation (*1*,*2*). Phytic acid changes the redox potential of Fe, ensuring quick removal of Fe(II) without simultaneous production of hydroxyl radicals (*1*). Animal studies show phytic acid reduces cancer cell proliferation (*7*). The increased solubility of phytate−mineral complexes may be a factor that explains reduced kidney stone formation (*1*). Moreover, calcium phytate at levels of 1−2% in the diet protects against dietary lead in human (*5*).

Phytic acid is regarded as an antinutrient as it can reduce the bioavailability of Fe, Zn, and other mineral micronutrients. Although fiber, tannins, oxalic acid, goitrogens, and heavy metals are also considered to be antinutrients, phytic acid is one of the most common antinutrients in the seeds of legumes and cereals. High concentrations of phytic acid in foods can limit mineral micronutrient bioavailability, especially in human populations that are mainly dependent on cereal and legume diets (*6*).

To reduce problems associated with phytic acid in animal feed, mutations that reduce the levels of seed phytic acid have been identified in the past decade in major crops such as maize, barley, rice, wheat, and soybean (*8*−*10*). Plants that express low phytate mutations produce 50−95% less phytic acid (*3*). Animal studies demonstrate that substantial reductions in phytic acid levels in feed lead to improved Ca and Zn utilization (*11*, *12*). However, long-term dietary effects of the reduction are unknown due to the long interval between experimental findings and their adoption in the production of large quantities of low-phytate foods.

Lentils are a part of the daily diet of many vegetarians as well as people in developing countries. On a global scale, consumption of lentils is growing at a much higher rate compared to most crops, especially other pulse crops, presumably because in whole food form lentils cook more quickly than many other grains (*13*).

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Lentils have a high protein content and are also a good source of Fe, Zn, and Se (*14*, *15*). Annual world lentil production is now approximately 4 million metric tons, about 0.9 million metric tons (22%) of which is grown in Canada, primarily in Saskatchewan (*16*). The proportion of world lentil production originating from Canada is steadily increasing (*13*), and >90% of Canadian lentils are exported to more than 100 countries in Europe, the Middle East, and South Asia (*13*). Health problems due to micronutrient malnutrition affect more than half of the world's population (*6*). As lentils are a significant food source in many countries where malnutrition is prevalent, lentils with lower concentrations of phytic acid may contribute to solutions for human micronutrient malnutrition, especially for South Asian populations where micronutrient malnutrition is more prominent.

The objectives of this study were to determine (1) the concentration of phytic acid in seeds of commercial lentil varieties grown in Saskatchewan, Canada; (2) the distribution of phytic acid concentration in whole lentil seeds and in seed fractions to assess the impact of postharvest processing on final phytic acid levels; and (3) the impact of boiling on the stability of phytic acid concentration in selected lentil genotypes. The knowledge gained is fundamental for developing a biofortification strategy for lentil.

MATERIALS AND METHODS

Materials. Standards, chemicals, and high-purity solvents used for phytic acid extraction and HPLC analysis were purchased from Alfa Aesar, a Johnson Matthey Co. (Edmonton, AB, Canada) and Sigma-Aldrich Co. (St. Louis, MO) and used without further purification. Water (distilled and deionized; ddH_2O) was purified by a Milli-Q Water System (Millipore, Milford, MA) to a resistance of ≥18 mΩ.

Lentil Seed Samples. Field experiments were conducted on 19 lentil varieties in Saskatoon and Kyle, SK, Canada. Lentil seed samples were obtained from regional variety trials conducted in 2005 and 2006 by the Crop Development Centre (CDC), University of Saskatchewan, Canada. The countries of major consumption of the lentil classes used for this study have been described (*15*). Subsamples of seeds for determination of phytic acid concentration were taken randomly from the entire harvested lot of each of three replicated randomized field plots at each location. Subsamples of 10−20 g of harvested lentil seeds (14% moisture, wet mass basis) were air-dried and stored at −20 °C until analyzed.

Processing and Cooking. Seed samples of 250−500 g each for three genotypes, CDC Greenland (large green), CDC Robin (extra small red), and Queen Green (green cotyledon), were obtained from three replicated plots at Saskatoon and Kyle in 2008. A seed sample of Pardina, one of the leading market classes of lentil consumed in Spain, was imported by Simpson Seeds Inc. (Moose Jaw, SK, Canada) and used as a reference sample to compare its processing and cooking quality with that of the Canadian cultivars. Seeds were dehulled in a Satake TM-05 grain testing mill (Satake Engineering Co. Ltd., Japan), then carefully separated by hand into seed coat, embryo, and cotyledon fractions. Each seed fraction was analyzed for phytic acid concentration as described below. For the cooking experiment, 100 g samples of lentil were rinsed with ddH_2O for 3 min, with the rinsewater removed and reserved for phytic acid analysis. Five hundred milliliters of ddH_2O was added to the sample, which was left at room temperature for another 10 min followed by heating on a hot plate (Cole-Parmer, model 4817, Chicago, IL) for 20 min at 80 °C until the seeds became tender. Rinse water and cooked lentils with their water were analyzed for phytic acid concentration.

Phytic Acid Analysis. Each replicated seed sample was prepared using the modified phytic acid extraction method described by Talamond et al. (*17*). A 100 mg sample of finely ground whole lentil was introduced into a 15 mL polystyrene conical tube (17 × 120 mm) fitted with a screw-cap. Ten milliliters of 0.5 M HCl was added and the mixture heated with stirring for 5 min by immersing the vial in boiling water. The sample was then centrifuged at 4000*g* for 3 min, and the supernatant was recovered.

Table 1. Gradient Chromatography Conditions for the Separation of Phytic Acid

time (min)	A[a] (%)	B[a] (%)	C[a] (%)
0	35	2	63
2	65	2	33
9.5	65	2	33
10.5	35	2	63
15	35	2	63

[a] Mobile phases used were 130 mM sodium hydroxide (A), deionized water/isopropanol (50:50, v/v) (B), and water (C).

Extracted phytic acid was decomplexed through the addition of 1.5 mL of 12 M HCl.

The high-performance anion exchange (HPAE) separation and conductivity detection of phytic acid was similar to the methods previously reported by Talamond et al. (*17*). A Waters 2695 separation module attached to a Waters 432 conductivity detector was used for HPAE analysis (Waters, Mississauga, ON, Canada). The separation was achieved using an Omnipac Pax-100 anion exchange column (250 × 4 mm i.d.) equipped with an Omnipac Pax-100 (8 μm) guard column (Dionex, Sunnyvale, CA) and an anion suppressor ASRS 300 4-mm (Dionex). Mobile phases used were 130 mM sodium hydroxide (A), deionized water/isopropanol (50:50, v/v) (B), and water (C). The flow rate of the gradient (**Table 1**) was 1.0 mL min^{-1} with a total run time of 15 min. Seeds of two low phytic acid pea mutant genotypes, 1-150 and 1-2347, and one normal phytic acid pea genotype, CDC Bronco, were used as laboratory reference materials. The phytic acid concentrations of these samples were 2.2 ± 0.001 mg g^{-1} for 1-150, 3.9 ± 0.001 mg g^{-1} for 1-2347, and 7.4 ± 0.001 mg g^{-1} for CDC Bronco. These reference samples were periodically analyzed to ensure the validity of the phytic acid analysis method. The error tolerance was <0.01% for all laboratory reference samples. Phytic acid phosphorus (P) was calculated from the weight ratio of the number of P atoms per phytic acid molecule to the phytic acid molecular weight (1:3.56).

Statistical Analysis. The experimental design was a randomized complete block design with three replicates at two locations for 19 genotypes over 2 years. Subsamples of lentil seeds for the determination of phytic acid were taken randomly from the entire harvested sample of each of the field plots. Data were analyzed separately for each location and year combination. Analysis of variance was performed using the General Linear Model procedure (PROC GLM) of SAS version 8.2 (*18*). Means were separated by Fisher's protected least significant difference (LSD) at $p < 0.05$.

RESULTS

Combined statistical analysis across locations and years showed variation in phytic acid concentration in lentil seeds was significant ($p < 0.05$) for location, replication, and the interaction between location and year (data not shown). As observed with most quantitative genetic traits, the interaction between location and year showed the most variation. This significant interaction may due to environmental variation such as soil conditions, weather patterns, and crop management practices. As a result, data were analyzed separately for each location and year (**Table 2**).

Significant genotypic differences in phytic acid concentration in lentil seeds were observed for both locations and years (**Table 2**). In both 2005 and 2006, lentils grown at Saskatoon had greater mean phytic acid concentrations (3.8−4.5 mg g^{-1}) compared to those from Kyle (2.0−3.4 mg g^{-1}).

Phytic acid concentration in the whole lentil seeds varied 1−2-fold across the locations, and, on average, seeds of some genotypes had 36−40% more phytic acid than others (**Table 3**). Two of the large green genotypes (CDC Sedley and CDC Plato) and two of the small green genotypes (Eston and CDC Milestone) had the lowest mean phytic acid concentrations (2.5−2.8 mg g^{-1}) over both years and locations (**Table 3**). Lentil genotypes from the

small red market class (CDC Blaze and CDC Impact) tended to accumulate higher concentrations of phytic acid in their seed compared to those from the extra small red market class (CDC Robin, CDC Rosetown, and CDC Imperial).

The distribution of phytic acid concentration in each of three seed fractions was determined for selected genotypes from four different market classes. Each market class is preferred by consumers in specific markets. CDC Greenland (large green), CDC Robin (extra small red), and Queen Green (green cotyledon) are commercially grown cultivars in Saskatchewan.

Table 2. Phytic Acid Concentration in Seeds of 19 Lentil Genotypes Grown at Two Different Locations in Saskatchewan, Canada, in 2005 and 2006

		phytic acid concn (mg g^{-1})			
year	location	minimum	maximum	mean (SE)[a]	genotype effect[b]
2005	Saskatoon	1.3	7.6	4.5 (0.01) a	*
	Kyle	1.3	4.8	2.0 (0.02) b	*
	mean			3.3 (0.07)	
2006	Saskatoon	2.1	6.6	3.8 (0.01) a	*
	Kyle	2.2	4.2	3.4 (0.04) b	*
	mean			3.6 (0.07)	

[a] Different letters indicate significant differences at $p < 0.05$. SE, pooled standard error of mean calculated from mean square of ANOVA for each location ($n = 57$). [b] Genotype effect was significantly different at $p < 0.05$.

The Spanish brown cultivar Pardina is a popular traditional lentil consumed mainly in Spain. These four cultivars were chosen to provide representative assessment of phytic acid distribution for uncooked seed fractions and cooked whole seeds (**Table 4** and **Figure 1**). Queen Green has significantly less phytic acid concentration compared to CDC Robin (**Table 4**). Pardina, which was grown in Spain in the 2007−2008 season, had a considerably higher amount of total seed phytic acid concentration (12.4 mg g^{-1}) than found in CDC Greenland (4.9 mg g^{-1}), CDC Robin (5.5 mg g^{-1}), or Queen Green (4.9 mg g^{-1}). The embryo axis fraction was enriched with phytic acid in comparison to cotyledon and seed coat fractions for all four lentil genotypes (**Table 4**).

Many lentils, particularly the red cotyledon types, are usually decorticated into whole or split form prior to cooking, and the remaining seed coat and embryo fractions are used as animal feed ingredients. Phytic acid stability was assessed in the cooking experiment with the same four lentil genotypes (Pardina, CDC Greenland, CDC Robin, and Queen Green) (**Figure 1**). The cooking process significantly reduced the phytic acid concentration in all four lentil genotypes: 99% in Pardina and > 50% for the other three genotypes.

DISCUSSION

Phytic acid is naturally present in all plants. The phytic acid and its mineral complexes reflect different chemical and biological

Table 3. Comparison of Phytic Acid Concentrations in 19 Lentil Genotypes Grown in Saskatchewan, Canada, in 2005 and 2006

		mean phytic acid concn[a] (mg g^{-1})		
genotype	market class	Saskatoon (two years)	Kyle (two years)	mean (two locations)
CDC Blaze	small red	4.4 abcd	4.4 a	4.4
CDC Viceroy	small green	5.8 a	2.6 bc	4.2
Laird	large green	5.3 a	2.9 b	4.1
CDC Impact	small red	5.2 ab	2.7 bc	4.0
CDC Redberry	small red	4.5 abc	3.3 ab	3.9
CDC Imperial	extra small red	5.2 ab	2.5 bc	3.9
Red Chief	large red	5.2 ab	2.4 bc	3.8
CDC Grandora	large green	4.6 abc	2.5 bc	3.6
CDC Rosetown	extra small red	4.6 abc	2.5 bc	3.6
CDC Robin	extra small red	4.1 abcd	2.9 b	3.5
CDC Rouleau	small red	4.1 bcd	2.9 b	3.5
CDC Greenland	large green	3.7 bcde	3.1 b	3.4
CDC Sovereign	large green	4.4 abcd	2.4 bc	3.4
CDC Meteor	medium green	3.9 bcd	2.7 bc	3.3
CDC Richlea	medium green	3.3 cde	2.5 bc	2.9
Eston	small green	3.2 cde	2.3 bc	2.8
CDC Sedley	large green	2.1 e	3.1 b	2.6
CDC Milestone	small green	2.8 de	2.3 bc	2.6
CDC Plato	large green	3.2 cde	1.8 c	2.5
mean		4.2	2.7	3.5
SE[b]		0.01	0.08	0.04

[a] Within a column, different letters indicate significant differences at $p < 0.05$. [b] SE, pooled standard error of mean calculated for phytic acid (mg g^{-1}) from mean square of ANOVA for each location ($n = 114$) and for mean of two locations ($n = 228$).

Table 4. Distribution of Phytic Acid Concentration in Lentil Seeds from Four Different Market Classes

		mean phytic acid (mg g^{-1})			
market class	genotype [a]	whole seed (± SE) [b]	embryo axis (± SE)	cotyledon (± SE)	seed coat (± SE)
Spanish brown	Pardina	12.4 ± 0.2	15.8 ± 0.2	10.4 ± 0.1	1.5 ± 0.1
large green	CDC Greenland	4.9 ± 0.1	4.8 ± 0.1	3.7 ± 0.1	1.2 ± 0.1
extra small red	CDC Robin	5.5 ± 0.1	8.4 ± 0.1	6.1 ± 0.1	1.2 ± 0.1
medium green	Queen Green	4.9 ± 0.1	10.5 ± 0.1	3.9 ± 0.1	0.9 ± 0.01

[a] Lentil genotypes CDC Greenland, CDC Robin, and Queen Green were grown in Saskatoon and Kyle, 2008 ($n = 18$), and Pardina was grown in Spain ($n = 3$). [b] SE, standard error.

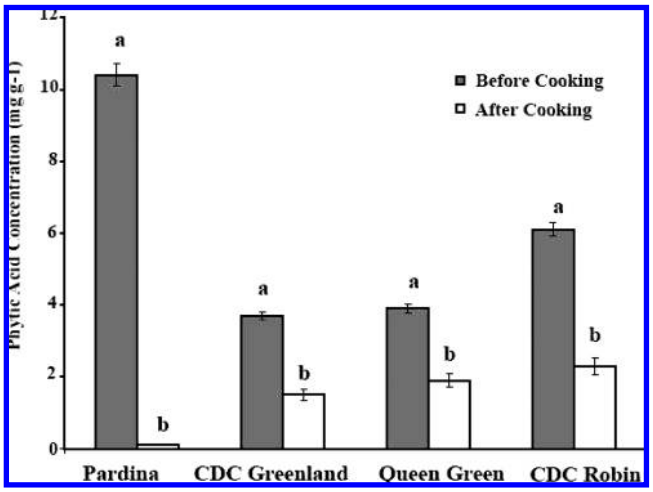

Figure 1. Change of phytic acid concentration in whole seeds of different lentil genotypes before and after cooking. Within a genotype, different letters indicate significant differences at $p < 0.05$.

properties that have significant impacts on human nutrition and health. Although phytic acid and its mineral salts have beneficial effects on human health such as decreasing the risk of heart disease, colon cancer, and renal stone formation, its role as a food antinutrient has been a major concern for mineral bioavailability for human populations that are mainly dependent on cereals and legumes. Attempts have been made to reduce the impact of phytic acid on food mineral bioavailability. More specifically, during the past decade, plant breeding efforts to reduce phytic acid were promoted as a solution to reduce the negative impact of phytic acid on human nutrition (*3*, *6*, *7*, *19*).

Mutants have been developed to reduce phytic acid concentrations in rice (*Oryza sativa* L.) (*20*), soybean (*Glycine max* L.) (*21*), wheat (*Triticum aestivum* L.) (*10*), maize (*Zea mays* L.) (*4*), and common bean (*Phaseolus vulgaris* L.) (*8*). To the best of our knowledge, none of the previously mentioned low phytic acid mutants are currently available for consumption as of 2008. The total phytic acid P levels in seeds of these mutant genotypes fall within ranges of 1.22−2.23 mg g^{-1} for rice, 1.77−4.86 mg g^{-1} for soybean, 1.24−2.51 mg g^{-1} for wheat, 3.3−3.7 mg g^{-1} for maize, and 0.52−1.38 mg g^{-1} for common bean (*4*, *8*, *10*, *20*, *21*). Data from the current study clearly show Canada-grown lentils are naturally low in phytic acid P (**Table 3**), as mean phytic acid P concentration in lentil samples from all locations and growing conditions ranged from 0.7 to 1.2 mg g^{-1} (phytic acid levels were from 2.5 to 4.4 mg g^{-1}). Therefore, lentil phytic acid concentrations were lower than the concentrations reported for low phytic acid mutants of rice, soybean, wheat, maize, and common bean.

In comparison to the phytic acid concentration found in seeds of other major grain legumes, our study found that lentils had lower phytic acid concentrations than kidney bean (11−17 mg g^{-1}), pea (2.2−8.2 mg g^{-1}), chickpea (4.9−6.1 mg g^{-1}), fava bean (10.1−13.7 mg g^{-1}), and soybean (10−14.7 mg g^{-1}) (*5*, *22*). Compared to other grain legumes, lentils may be a natural whole food source of vegetable protein with inherently low phytic acid concentration.

The production environment of the lentil crop may also have an effect on phytic acid concentration. Reports in the literature indicate that lentils grown in other locations around the world may have considerably higher phytic acid concentrations. For example, phytic acid levels reported for lentils grown in Bangladesh, India, and the United States ranged from 4.7 to 4.8 mg g^{-1}, from 10.1 to 11.0 mg g^{-1}, and from 8.3 to 8.8 mg g^{-1}, respectively (*23*−*25*). All of these studies used the colorimetric procedure, and therefore the phytic acid levels may in fact be lower, but even accounting for the method differential, the levels are higher than those reported in our study. The higher phytic acid levels found in lentils from these geographic locations could be attributed to genotypic variations, climatic differences, soil factors, or other unexplained reasons and may warrant further investigation. For example, the grain-filling period of lentils grown in Bangladesh, India, and the United States (and most other lentil-producing regions of the world) coincides with a period of rising temperatures. For northern temperate regions, the grain-filling period usually occurs at cooler and generally declining temperatures. This may partly explain why phytic acid concentrations are lower, through either a dilution effect on phytic acid concentration or a physiological effect on phytate accumulation, or both.

Our phytic acid analysis was based on anion exchange HPLC separation followed by conductivity detection as described by Talamond et al. (*17*). This procedure was followed after careful evaluation of the merits of different phytic acid determination methods. In the past, phytic acid was often quantified using colorimetric procedures as total phosphates or after separation of inorganic and organic phosphates (*26*). Although colorimetric procedures tend to be faster and less costly, they could overestimate phytic acid concentration by 27% or more compared to high-performance liquid chromatographic techniques due to lack of specificity (*17*, *27*). For example, the previously published phytic acid P values for rice (*20*), soybean (*21*), wheat (*10*), maize (*4*), and common bean (*8*) were based on the colorimetric procedures. Therefore, it could be argued that those reported values may have errors inherent to the colorimetric phytic acid determinations. In the present study phytic acid was carefully extracted and separated using HPAE and conductivity detection. This procedure enabled accurate quantification of study samples with $< 5\%$ error variability in the phytic acid level reproducibility of the laboratory reference materials. Using a signal-to-noise ratio of > 3, the detection limit was 0.001 m mol L^{-1}.

A previous study, using eight different lentil genotypes, reported that the phytic acid levels in the Canadian commercial lentils were from 6.2 to 8.8 mg g^{-1} (*27*). Although phytic acid extraction from lentil seeds was similar to the present study, the phytic acid analysis in the previous study was based on a colorimetric procedure. As described previously, errors inherent to the colorimetric procedures might have played a role in the overestimation of those commercial Canadian lentil samples. Analysis of a few samples by colorimetric and HPAE−conductivity detection by our research group also showed (data not shown) colorimetric procedures tend to overestimate phytic acid levels, supporting Talamond et al. (*17*). Although inorganic phosphate is removed prior to total phytic acid quantification in the colorimetric method, the overestimation could be partially attributed to the presence of particularly other phosphorylated phytates and residual inorganic phosphates.

Developing low phytic acid grains is a primary goal for improving the nutritional quality of many crops, especially those consumed in developing countries. Phytic acid chelates with minerals and metals, such as Ca, Mg, Zn, and Fe, and it forms insoluble salts that are not readily absorbed by humans. This antinutrient activity may severely impair the bioavailability of Zn and Fe. Phytic acid can also complex with proteins and may reduce digestibility and enzyme activity.

Phytates can have adverse effects on mineral uptake and metabolism in the human body. However, their impact is likely to be minimal if the micronutrient content of the diet is well above the recommended daily requirements (*28*). Our previous studies showed that lentils grown in Saskatchewan contain 425−673 μg of Se kg^{-1}, 73−90 mg of Fe kg^{-1}, and 44−54 mg kg^{-1} of Zn depending upon location, soil environment, and growing conditions (*15*, *29*). A serving of 100 g of dry lentils could provide substantial portions of the minimum recommended daily intakes of Se (80−120%), Fe (41−113%), and Zn (40−68%). Therefore, negative nutritional impacts of phytic acid may be reduced because the lentils have relatively high micronutrient concentration and low phytic acid concentration relative to other whole grains. It may be necessary to evaluate the impact of phytic acid in the context of the levels of other micronutrients and lentil serving sizes in a regular diet (*28*). It may also be useful to extend the analysis to measurements of bioavailability.

Our field data demonstrate Saskatchewan-grown commercial lentils are naturally low in phytic acid, and our lentil cooking experiment showed cooking further reduces total phytic acid. Reduction in phytic acid levels with cooking has been reported previously for whole green lentils, leading potentially to increased Ca and Mg bioavailability (*30*). However, the same study found that lentil texture also decreased during cooking. This reduction in cooking quality may not be of great importance for cooked dehulled lentils because most people consume these as a curry or soup.

In summary, phytic acid binds important micronutrients such as Fe and Zn, forming salts that are largely excreted. This phenomenon can lead to mineral depletion and micronutrient deficiency in humans. This potential negative impact is somewhat balanced by the fact that dietary phytic acid may play a beneficial health role, for example, as an antioxidant or anticancer agent. Therefore, the relative merits of dietary phytic acid must be evaluated in the context of typical diets of a developing and developed world. It is our view that consumption of lentils with low phytic acid could be part of the solution to the problem of micronutrient malnutrition in developing countries. We present evidence that lentils grown in the northern temperate cropping region of North America may be nutritionally unique because they produce seeds with relatively low phytic acid concentration combined with relatively high levels of the essential micronutrients Se, Fe, and Zn. Lentils with this biochemical profile could have the potential to provide significant amounts of essential micronutrients and contribute toward increasing micronutrient bioavailability in human populations. Our future work will address the genetics and physiology of seed phytic acid formation in lentils. It may be possible to develop biochemical phenotypes for individual lentil genotypes based on bioavailability studies and link this information to plant genetic studies to investigate the potential for biofortification.

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NOTE ADDED AFTER ASAP PUBLICATION

The original publication of September 2, 2009, contained errors in Table 3 and the third from last paragraph of text. These errors have been corrected with the publication of September 9, 2009.

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