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MINI REVIEW

Phytic acid in legumes: a review of nutritional importance and hydrothermal processing effect on underutilised species

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Abstract

Phytic acid (IP6), also known as inositol hexakisphosphate, a naturally occurring component of legume seeds, is traditionally regarded as an antinutrient. This report was aimed to provide information on hydrothermal processing effects and nutritional importance of phytic acid in legumes. As a strong chelating agent, phytic acid has the ability to form complexes with protein and mineral elements (e.g. Ca, Fe, Zn and Mg) and thus makes the nutrients unavailable for absorption and utilisation. Reduction of IP6 using soaking and hydrothermal methods enhances the bioavailability of protein and mineral elements. Low level of phytic acid in diets have some health benefit effects and thus classification of phytic acid as an antinutrient needs to be reconsidered.

1. Introduction

In many nations of the world, and particularly in developing countries, seeds of legumes make significant contributions to the protein intake of the large segment of the population. Seeds of legumes are important sources of nutritionally important nutrients such as protein and mineral elements (Ojo *et al*., 2014a). They are worldwide in distributions and are of many types. In recent years, more emphasis is being placed on the need for increased consumption of protein-rich diets. Although protein can be obtained from plants and animals, plant protein is being given preference because they are relatively cheaper and more available (Lewis *et al*., 2005; Ojo *et al*., 2014b). Moreover, proteins from plants unlike animal proteins are not generally associated with incidences of cardiovascular diseases and as such are gaining more attention as a component of food system (Adebowale *et al*., 2005). Legume seeds are the most widely used alternative sources of protein. In addition, legumes contain other beneficial, important nutrients such as lipids, carbohydrates, vitamins and mineral elements at different proportions (Adebowale *et al*., 2005; Fasoyiro *et al*., 2006; Ojo *et al*., 2014b). Seeds of legumes are generally low in oil but they are good sources of mineral elements and fibre (Ojo *et al*., 2016). It has been reported that regular consumption of legumes produces hypoglycemic effect, reduces occurrences of cardiovascular diseases and assist in weight management (Adebowale *et al*., 2005; Fasoyiro *et al*., 2012; Ojo *et al*., 2014a).

In spite of many benefits of their utilisation, legumes contain a number of toxic and anti-nutritional constituents. Although they are important sources of dietary protein, they probably contain a greater variety of toxic components than found in any other plant family. These toxic components occur naturally and they include saponin, tannins, cyanogens, goitrogens, hemagglutinin, phytic acid, estrogens, etc. (Smolenski *et al*, 1981; Fasoyiro *et al*., 2006; Adeyemo and Onilude, 2013; Ojo *et al.,* 2014a). These toxic components in legumes must be inactivated, reduced and/or removed before their nutritional values are to be fully realized. The toxic components interfere with normal growth of animals and man but fortunately can be removed and/or reduced by a number of processing procedures such as germination, fermentation, the heat of cooking and or by controlling other unit operations during processing. Problems such as these which generally require research and controlled processing must always be considered when less common sources of food like underutilised legumes are proposed for use to solve the problem of food deficiency -related diseases.

Phytic acid (IP6) occurs as a natural component of legumes (Aykroyd and Doughty, 2002; Ojo, 2015). The impact of different hydrothermal treatments on the

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concentration of phytic acid in some selected underutilised hard-to-cook legumes have been reported (Ojo *et al*., 2017a, 2017b). Hydrothermal processing treatments have been employed to alleviate the problem of prolonging cooking phenomenon in underutilised legumes (Ojo, 2015; Ojo, 2018a). This study reports the nutritional importance of IP6 and the effects of soaking at varying hydration levels and hydrothermal processing techniques on the IP6 content of some underutilised hard-to-cook legume seeds. Provision of information on the status of IP6 before and after processing will widen the scope of knowledge and encourage utilisation of these underutilised species that have the propensity of health-promoting benefits.

2. Phytic acid in legumes

Phytic acid, also known as inositol hexakisphosphate (IP6) is one of the naturally occurring toxic components of legume seeds. It is referred to as phytate in salt form. Sodium phytate is the most frequently used form of phytic acid. Seeds of leguminous plants contain phytic acid at varying concentrations. Phosphorous in many plant tissues including legumes are stored in form of phytic acid (Hellendoorn, 1999; Aykroyd and Doughty, 2002; Lewis *et al*., 2005). Phytic acid occurs mostly in seed coats of grains, nuts and seeds. As shown in Figure 1, phytic acid has the molecular formula of $C_6H_{18}O_{24}P_6$ while the molar mass is 660.04 g/mol. (Hellendoorn, 1999; Reddy and Sathe, 2002). If ingested, phytate cannot be absorbed or utilised by the human digestive system or any monogastric animal. This is because of the absence of endogenous enzymes such as phytase that can catalyse the hydrolysis of phytic acid to its component (Prattley *et al*., 2003). The concentration of phytic acid in the diet depends on the quantity in the legume seeds and the methods of processing.

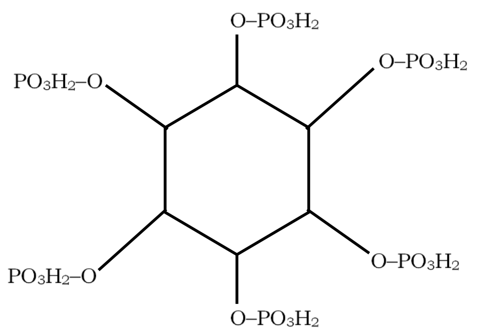

Figure 1. Structure of phytic acid (Molecular Formula: $C_6H_{18}O_{24}P_6$, Molar Mass: 660.04 g mol^{-1})
Source: Hellendoorn (1999), Reddy and Sathe (2002)

3. Phytic acid as an antinutrient

Phytic acid is a strong chelating agent. The structural formula of phytic acid gives it the ability to bind starch, proteins and mineral elements such as Fe, Ca, Mg, and Zn. Therefore, it can contribute to deficiencies of mineral elements in developing countries where most consumers depend on seeds of legumes and cereals for their mineral intake. Hence, it is an antinutrient. For those people with a particularly low intake of essential mineral elements especially infants and pregnant mothers, this effect of chelating property can be very undesirable (Hurrel *et al*., 2003; Ojo, 2015). Chelating property of phytic acid can lead to the deficiency of iron in infant complementary foods during the weaning period resulting in a major consequence of retarded psychomotor and mental development (Hurrel *et al*., 2003). Generally, chelates of phytic acid and mineral elements are soluble at low pH but are almost absolutely insoluble at physiological pH and hence, considered as the principal cause of decreased bioavailability of the chelates (Carnovale *et al*., 2007). Bioavailability of mineral elements in nutrition importance is influenced by a number of factors. Phytic acid is an inhibitor while ascorbic acid enhances iron absorption by reducing the effect of phytic acid on iron. Degradation of phytate has been reported to improve iron absorption from cereal-based complementary foods provided the foods are mixed with water and not milk (Hurrel *et al*., 2003). Therefore, phytic acid as a complex-forming agent should be given a high level of attention in the nutrition of legumes (Carnovale *et al*., 2007).

Much attention has been given to the ability of phytic acid to form complexes with mineral elements and formation of chelates that have reduced availability. However, there is a dearth of information on the interaction of phytic acid with proteins in legumes. Studies on soya bean describing interaction and formation of phytate–protein complexes were reported. Phytic acids also have the ability to form a complex with niacin, a basic, leading to a vitamin deficiency condition known as pellagra (Carnovale *et al*., 2007). The decrease in the protein content of *Canavalia ensiformis* during processing was observed during hydrothermal processing. The decrease, in part, was most probably due to interaction between phytic acid and protein molecules (Ojo, *et al*., 2018). However, the nature of such interaction with phytate is not well understood yet.

4. Phytic acid, a phytonutrient with therapeutic benefits

Although phytic acid has the ability to chelate mineral ions and making them unavailable for absorption and utilisation by the body tissues, it can also be considered as a phytonutrient because of its antioxidant property (Reddy and Sathe, 2002). The chelating effect of phytic acid may serve to prevent, inhibit or even cure some cancers by depriving those cancerous cells of the minerals they need to reproduce (Graf and Eaton, 1990; Reddy and Sathe, 2002; Shamsuddin, 2002). The deprivation of essential mineral like iron would much like other broad treatment for cancers, also have negative effects on non-cancerous cells. This may probably affect other cells in the body that require iron such as red blood cells (Hurrel *et al*., 1992). It is believed that phytic acid found in the fibre of legumes and grain is the major ingredient for preventing colon cancer and other cancers (Vucenik and Shamsuddin, 2003). Phytic acid may have more therapeutic value when added to water rather than when naturally absorbed in foods because it is difficult to free from fibre (Hurrel *et al.,* 1992; Hortz *et al.,* 2001).

In general, foods including legumes must be well cooked in order to free phytic acid from the fibre and enable it to be absorbed in the gastrointestinal system. Phytic acid is usually associated with insoluble fibre or the bran which is difficult to digest: phytic acid is rarely associated with soluble fibre (Vucenik and Shamsuddin, 2000). The chelating properties of IP6 may also prevent cancer by reducing oxidative stress in the lumen of the intestinal tract (Vucenik and Shamsudin, 2003).

In food processing, IP6 has found use as a preservative (Hurrel *et al.,* 1992; Hortz *et al.,* 2001). In recent times, IP6 has been reported to lower blood glucose by reducing the rate of starch digestion and slow down the emptying of the gastric. Thus, IP6 may be of significant health benefits to diabetics especially type II diabetic which is believed to be associated with eating habit. Addition of purified sodium phytate to diet has been demonstrated to reduce glycemic index, lower plasma cholesterol and triglyceride levels (Seaman *et al.,* 2003; Xu and Chang, 2009; Ojo, 2015). During digestion, phytic acid releases inositol. Although inositol is not an essential nutrient, it has been observed that it might reduce depression. Moreover, IP6 may also reduce inflammation (Sharma and Kapoor, 1996; Hurrel *et al.,* 2003).

5. Effect of soaking on the phytic acid content of legume seeds

After soaking the legume seeds of some underutilised legumes in distilled water to varying hydration levels (0, 10, 25, 50, 75 and 100) at ambient temperature (23-28°C), the effect of soaking on the concentration of phytic acid was examined. (Ojo *et al.*, 2017a; Ojo *et al.,* 2017b; Ojo *et al.*, 2018). Changes in the concentration of phytic acid in the legume seeds after soaking to varying hydration levels are shown in Table 1. For each of the legume seeds recorded in Table 1, there were significant differences (p<0.05) in the concentration of phytic acid at varying hydration levels. The percentage reduction in the phytic acid for *Mallotus subulatus* ranged from 4.71-12.06% while that of *Cassia hirsutta* was lower, ranging from 0.73-6.20%. Reduction

Table 1. Concentration of phytic acid (mg/g) in some underutilized legume seeds before and after soaking at varying hydration levels

Legume sample	Hydration level (%)					
	0	10	25	50	75	100
Mallotus subulatus 1(White)	71.34±0.72^e	67.98±0.53^d {4.71}	65.60±0.25^c {8.05}	63.57±0.44^b {10.89}	62.75±0.60^a {12.04}	62.73±0.45^a {12.06}
Cassia hirsutta	56.26±0.18^f	55.85±0.20^e {0.73}	55.07±0.15^d {2.12}	54.81±0.31^c {2.58}	52.89±0.05^b {5.99}	52.77±0.08^a {6.20}
Canavalia ensiformis	59.28±0.26^f	58.56±0.10^e {1.21}	58.09±0.28^d {2.01}	56.67±0.55^c {4.40}	55.34±0.41^b {6.65}	55.21±0.07^a {6.87}
Vigna subterranean 1(Cream)	70.80±0.49^f	68.87±0.38^e {2.73}	68.25±0.40^d {3.60}	66.32±0.22^c {6.33}	65.24±0.22^b {7.85}	65.03±0.10^a {8.15}
Vigna racemosa	63.15±0.28^d	63.02±0.04^c {0.21}	62.71±0.30^b {0.69}	61.42±0.21^a {2.74}	61.41±0.30^a {2.76}	61.41±0.08^a {2.75}
Mallotus subulatus 2 (Brown)	69.53±0.43^f	65.85±0.30^e {5.29}	63.48±0.20^b {8.70}	62.67±0.31^c {9.86}	62.08±0.14^b {10.71}	60.99±0.28^a {12.28}
Vigna subterranean 2 (Mottled)	58.45±0.34^d	55.40±0.20^c {5.22}	54.89±0.40^b {6.09}	54.45±0.31^a {6.84}	54.41±0.30^a {6.91}	54.41±0.23^a {6.91}
Sphenostylis sterocarpa	71.78±0.80^d	68.38±0.25^c {4.74}	67.82±0.52^b {5.52}	66.57±0.41^a {7.26}	66.55±0.36^a {7.29}	66.55±0.29^a {7.29}

Sources: Ojo (2015), Ojo *et al*. (2017a, 2017b), Ojo (2018a, 2018b).
Values above are means ±SD of three replicates on dry basis. Values with different subscripts in the same row are significantly different (p<0.05).
Values in parenthesis represent the percentage loss.

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of phytic acid in *Canavalia ensiformis* was in the range of 1.21-6.87% (Ojo *et al.*, 2017a; Ojo *et al.*, 2017b; Ojo *et al.*, 2018). These percentage reductions in the phytic acid content of legume seeds were comparable to result obtained for *Mucuna flagellipes* that experienced 27.90% reduction in phytic acid after soaking for 6 hours and 36.0% reduction after soaking for 24 hours at ambient temperature (Udensi *et al*., 2008). A similar reduction of 9.7% was reported for *Sesbania rastrata* after soaking (Siddhuraju *et al*., 2002). However, soaking did not change the concentration of phytic acid in *Sesbania aculenta* (Siddhuraju *et al.*, 2002). The percentage reduction in phytic acid content decreased with increasing hydration levels (Table 1). The decrease in the concentration of phytic acid of the legume seeds during soaking was partly due to leaching (Siddhuraju and Becker, 2001). Reduction of phytic acid could also be due to degradation of the phytate molecule in the seeds (Vijayakumani *et al.*; 2007; Ojo *et al.,* 2018).

6. Effect of hydrothermal treatments on the phytic acid content of legume seeds.

Earlier studies have reported the application of four hydrothermal methods (boiling at atmosphere pressure BAP, boiling at elevated pressure BEP, steaming at atmosphere pressure SAP and steaming at elevated pressure SEP) to processing of some underutilised legumes (Ojo, 2015; Ojo *et al*., 2017a; Ojo *et al.,* 2017b). The phytic acid content of the raw and processed seeds was analysed. All the four hydrothermal methods caused a varying reduction of IP6 content of the legume seeds. (Table 2). The percentage loss was dependent on the type of legume seeds and the method of processing (Ojo *et al*., 2017a; Ojo *et al.*, 2017b).

Boiling of *Mallotus subulatus* at atmospheric pressure reduced its phytic acid content by 58.90% while boiling and steaming of *Canavalia ensiformis* at atmospheric pressure caused a reduction of 63.26 and 57.02%, respectively; boiling and steaming at elevated pressure led to reduction of 62.97 and 56.41%, respectively (Ojo *et al*., 2017a; Ojo *et al*., 2018). The reduction ranges of 21.6-21.9% of phytic acid were observed when lentil was cooked using different cooking treatments (Xu and Chang, 2009). In 2009, Wang *et al*. reported 15.90% reduction in phytate level during cooking. Also, Elhardallon and Walker (1994) reported a higher percentage reduction of 60.50% in phytic acid after cooking of lentil. These discrepancies may be due to various differences in the legume samples, agronomical factors in cultivation and variation in processing procedures. Apart from the use of hydrothermal treatments, efforts have been made to reduce IP6 content of food by using methods such as germination, fermentation, roasting and application of varying doses or irradiation (Sharma and Kapoor, 1996; Siddhuraju *et al.,* 2002; Udensi *et al*., 2008).

Table 2. Phytic acid content of some underutilised legume seeds as influenced by hydrothermal processing methods (mg/g)

Legumes	Processing conditions				
	RS	BAP	SAP	BEP	SEP
Mallotus subulatus 1 (White)	71.34±0.72^{d}	29.32±0.22^{a} {58.90}	32.63±0.51^{c} {54.26}	31.03±0.42^{b} {56.50}	31.40±0.28^{b} {55.99}
Cassia hirsutta	56.26±0.18^{d}	21.30±0.23^{a} {62.14}	24.75±0.44^{b} {56.01}	24.06±0.11^{b} {57.23}	25.81±0.26^{c} {54.12}
Canavalia ensiformis	59.28±0.26^{c}	21.78±0.20^{a} {63.26}	25.48±0.53^{b} {57.02}	21.95±0.46^{a} {62.97}	25.84±0.61^{b} {56.41}
Vigna subterranean 1(Cream)	70.8±0.47^{c}	21.38±1.01^{a} {69.80}	24.97±1.03^{b} {64.73}	21.79±0.56^{a} {69.22}	25.56±0.51^{b} {63.90}
Vigna racemosa	63.15±0.28^{d}	21.55±0.42^{a} {65.87}	25.87±1.01^{c} {59.03}	23.74±0.30^{b} {62.41}	25.10±0.57^{c} {60.25}
Mallotus subulatus 2 (Brown)	69.53±0.43^{c}	29.50±0.06^{a} {57.57}	31.93±0.71^{b} {54.08}	30.13±0.24^{a} {56.67}	32.67±0.55^{b} {53.01}
Vigna subterranean 2 (Mottled)	58.45±0.34^{c}	18.45±0.17^{a} {68.43}	20.75±0.32^{b} {64.50}	18.96±0.45^{a} {67.56}	20.75±0.51^{b} {64.50}
Sphenostylis sterocarpa	71.78±0.80^{d}	24.22±0.65^{a} {64.26}	28.41±0.40^{c} {60.42}	25.04±0.21^{b} {65.11}	28.68±0.42^{c} {60.04}

Sources: Ojo (2015), Ojo *et al.* (2017a, 2017b), Ojo (2018a, 2018b).
Values above are means ±SD of 3 replicates on dry basis. Values with different subscripts in the same row are significantly different (p<0.05). Values in parenthesis represent the percentage decrease.
RS = raw dried sample; BAP = boiling at atmospheric pressure; SAP = steaming at atmospheric pressure; BEP = boiling at elevated pressure; SEP = steaming at elevated pressure.

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No significant differences ($p<0.05$) were observed in phytic acid content between the raw legume seeds and those subjected to irradiation doses of 2, 4 or 6 KGy (Siddhuraju *et al.,* 2002). There are conflicting reports about the potential health hazard of exposing food crops to varying doses of irradiations. As shown in Table 2, all the four hydrothermal processing methods resulted in the reduction of the concentration of phytic acid of the legumes studied. Reduction in the level of IP6 after hydrothermal treatment may be due, in part, to the formation of insoluble complexes between phytic acid and other food components such as mineral elements and protein (Xu and Chang, 2008; Ojo *et al*., 2016; Ojo *et al.,* 2018). Also, decrease in phytic acid may also be due to chemical degradation of phytic acid to penta and tetraphosphate (Siddhiraju *et al.,* 2002; Xu and Chang, 2009; Ojo *et al.,* 2018). A number of processing methods such as fermentation, dehulling, soaking, germination as well as treatment with phytase have been employed to degrade or reduced phytic acid in foods and improve nutritional quality (Fagbemi *et al.,* 2005; Adeyemo and Onilude, 2013). Germination has been reported to improve thiamine, *in vitro* iron and calcium bioavailability and *in vitro* starch and protein digestibility of legumes (Reihaneh and Jamuuna*,* 2006).

7. Conclusion

Traditionally, phytic acid is considered a naturally occurring antinutrient in legumes. The presence of toxic components or antinutrients in legumes impairs the digestion of nutrients such as protein and mineral elements like Mg, Fe, Ca and zinc and hence reduce the nutritional values. However, results of recent studies indicate that a low level of IP6 had health benefit as an antioxidant. Phytic acid plays an important role in controlling blood glucose, hypercholesterolemia and arteriosclerosis. Reduction of IP6 through processing, such as hydrothermal treatments, enhances bio-availability of protein and mineral elements in legume and at the same time, the low level of IP6 in the cooked legume has some health benefits to consumers. However, it is expedient to study the minimum or appropriate amount of IP6 in the diet necessary to meet the human physiological need. In view of the health benefits, the term antinutrient which has hitherto been used to describe a food component such as phytic acid needs to be reconsidered. Thus, consumption of legume seeds containing a low level of phytic acid has health-promoting effects.

Conflict of interest

The author declares no conflict of interest.

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