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Improving Human Dietary Choices Through Understanding of the Tolerance and Toxicity of Pulse Crop Constituents

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Abstract

Chickpea, dry bean, dry pea, and lentil are prominent dietary grain legumes commonly referred to as pulses. Pulses have been a staple component of the human diet for more than 8,000 years; however, in the last 70 years they have virtually disappeared from most Western diets. Reduced intake has occurred concomitantly with inadequate dietary fiber consumption and the onset of the obesity pandemic. Misinformation about tolerance and toxicity of several pulse crop constituents remains a barrier to public health efforts to increase dietary intake. Of particular concern are lectins which participate in agglutination reactions with cell surface proteins and galacto-oligosaccharides which have been associated with intestinal discomfort and flatulence. The scientific basis of these concerns is reviewed.

Keywords

Dietary fiber; galactans; grain legumes; lectins; oligosaccharides; pulse crops; tolerance; toxicity

Introduction

From the dawn of agriculture, which developed independently in at least seven regions of the world, a grain legume was paired with a cereal grain as staples in the diet for the majority of those ancient centers of domestication [1]. The Food and Agriculture Organization of the World Health Organization recognizes 17 grain legumes, commonly referred to as pulses, as human food sources. Of these four are globally pre-eminent, i.e., chickpea, dry bean, dry pea, and lentil [2]. They are rich sources of dietary protein and fiber [3]. However, over the last 70 years, pulses have been displaced from the typical Western diet by animal products and protein isolates (e.g., whey and soy) which are devoid of dietary fiber [1]. This break from the historical pattern of consuming cereal grains and pulses in a 2:1 ratio in the diet has coincided with a well-documented gap between actual and recommended levels of dietary fiber and that gap has persisted in developed countries for many decades [1;4]. The concentration of fiber (g per 100 g of edible portion) in pulses exceeds other commonly

Conflict of Interest
The author declares that there are no conflicts of interest.

promoted sources by 2–3 fold [2]. Consequently a reawakening of interest in pulse crops is occurring [5].

It is striking that the decline in pulse consumption has occurred concomitantly with an increase in chronic disease prevalence, particularly in developed countries [6]. In fact, chronic disease prevalence is inversely correlated with pulse consumption [7]. Whether or not this relationship is causal is unclear [3]. However, given the emerging evidence that gut health is a determinant of chronic disease risk, and the prominent role of dietary fiber in promoting gut health [8–14], a causal link among pulse consumption, gut health, and chronic disease risk is plausible. Attention to the importance of pulses as a central component of the global diet was recently highlighted by the declaration of the International Year of the Pulse by the World Health Organization in 2016 [15]. Not surprisingly, many questions result when a type of food intended for markedly increased consumption is "reintroduced to the consumer" [16]. The scientific literature reflects a burst of activity in the publication of papers that address the issues of pulse toxicity and tolerance. Those issues are the topic of this brief review and analysis.

Consumer perspective

While pulse consumption is high in many developing countries (200 to 300 g/d), in developed countries like the United States and Canada, average intake is estimated to be 10g/d [17;18]. Because of this, a dual categorization for pulses was formulated into the U.S. Dietary Guidelines, i.e., pulses were classified as vegetables or a protein source depending on amount eaten [19]. This served to de-emphasize the importance of pulse consumption, and the distinctiveness of pulses was blurred by lumping them into the generic category of legume which includes both grain legumes that have very low levels of lipid, and oil seed legumes, e.g., soy bean and peanuts that have high fat content and reduced fiber per 100 g edible portion. The term legume also includes the immature pods of these plants which differ markedly in nutrient content relative to the seed [1]. An argument for doing this was that Americans were unfamiliar with the term "pulse", and therefore the name should be avoided. This was an unintended source of confusion to the busy 21st century convenience oriented consumer. Fortunately, the newest version of the U.S. Dietary Guidelines has addressed these issues. However, with the reawaking of interest in pulses, questions raised by dietary fads such as the "Paleo Diet" about the safety of pulse consumption, i.e., anti-nutrients such as lectins and trypsin inhibitors, require clarification [20;21]. Moreover, from a clinical perspective there is an unrelated but overlapping spectrum of intestinal symptoms that are associated with both pulse intolerance and toxicity [22–25]. The etiology of discomfort differs as does the method of mitigation. Our intent is to examine these issues since concerns about tolerance and toxicity constitute barriers to increasing pulse consumption.

Pulse crop toxicity

Lectins are a class of glycoproteins widely distributed in plant species and generally found in the highest concentrations in the seed, particularly the seed coat where they play a role in plant defense mechanisms [26]. The toxicity of lectins in raw seed is linked to their binding to carbohydrate moieties of cell surface proteins following consumption in what is referred to as protein agglutination [27–30]. In the intestine, lectins can bind to proteins in the brush border villi resulting in inhibition of nutrient uptake (an anti-nutrient effect). Lectins can also alter tight junction integrity among intestinal mucosal cells resulting in increased permeability, sometimes referred to as “leaky gut syndrome”. When absorbed, lectins can bind with cells in the circulatory system with implications relative to red blood cell stability, immune surveillance, and immune reactivity. Because of these effects, there is concern about food lectins and it is well documented that raw pulses have significant concentrations of these proteins [26;31;32]. The acute effects of consuming raw pulses that are linked to active lectins include nausea, vomiting, and diarrhea. Chronic subacute toxicity is manifest as decreased nutrient uptake, increased inflammation, hemolysis, and immune system disorders. However, beneath the surface of this concern, the science reveals that all pulse crops are not created equal with respect to the quantity and type of lectins that they contain [33;34]. In fact, many lectins have limited agglutination activity in humans [25]. Of even greater importance is that lectins are relatively unstable in the presence of moisture and heat and that when recommendations for soaking and cooking of pulses are followed before they are consumed, the biological activities of lectins can be completely eliminated [24]. The confusion among consumers and many health professionals about whether pulses are a safe food source has several origins: 1) failure to distinguish between results from scientific papers reporting effects of consumption of raw seed versus properly soaked and cooked seed [24;35;36], 2) failure to acknowledge that the growing interest in pulse lectins, isolated from raw seed for biomedical applications, has no bearing on the dietary consumption of properly cooked pulses [27;30;37–41], and 3) failure to emphasize that case reports about the acute toxicity of under cooked pulses has no bearing on the safety of properly prepared pulses [42]. Missing from the contemporary literature is an authoritative analysis and publication of the conditions that render each specific pulse crop safe for consumption based on: 1) pulse type, market class, and variety, 2) whether the pulse variety is of the fast cook or hard to cook category [43–48], and 3) the location at which the pulse is prepared, e.g., sea level versus at higher altitude, since this conceivably could affect the cooking duration required to inactivate lectins (Table 1). In the absence of clarity, confusion and misinformation will persist. One other class of toxicants that is sometimes mentioned in discussions of pulses is trypsin inhibitors which can decrease dietary protein bioavailability [49–52]. As with lectins, not all pulse crops are created equal in terms of amount of trypsin inhibitor present and the same conditions of soaking and cooking that destroy lectins similarly eliminate trypsin inhibitor activity.

Pulse crop tolerance

Pulses are a rich source of dietary fiber, a complex mixture of carbohydrates that are resistant to digestion and absorption in the intestinal tracts of most monogastric animals including humans [1]. As noted in the Introduction, dietary fiber has potent prebiotic effects which are associated with human health as well as chronic disease prevention and control. Pulses are generally eaten as a whole food and this accounts in part for the high concentration of dietary fiber that pulses contain per 100 g edible portion. However, while not a toxic effect in the traditional sense, many individuals have an adverse response to the consumption of pulses with symptoms of intestinal discomfort and increased flatulence [53]. Frequently these effects have been attributed to the oligosaccharide component of pulses [22;23]. Pulses contain primarily galacto-oligosaccharides: raffinose, stachyose, and verbascose which are not digested in the small intestine because of the absence of galactosidases [1;2]. Consequently, these oligosaccharides are fermented in the colon with the release of gas. However, whether this is the primary source of pulse associated flatulence has recently been questioned [23]. Rather, the physical form in which other fiber components reside in the pulse seed may affect the amount of undigested carbohydrate that reaches the colon. Recent reports also indicate that pulse tolerance is: 1) affected by an individual's gut associated microbiome, 2) dependent on how an individual reabsorbs intestinal gases such as carbon dioxide, hydrogen, methane, and nitrogen (all of which are odorless) for elimination via the lung or kidney, and 3) affected by the manner in which an individual further metabolizes gases that are either ingested or formed during intestinal fermentation with differences existing in utilization by other intestinal microbes versus the amount eliminated via the mouth or anus [10;22;23;54–56] (Table 2). Each of these factors appears to have a genetic component that contributes to differences among individuals in the intestinal discomfort that they experience. In addition, a recent report found that most individuals who experience flatulence adapt to pulse consumption within a few weeks if intake levels are maintained [23]. Nonetheless, it is common for persistent symptoms of intestinal discomfort to be evaluated clinically [57]. For those individuals who remain intolerant, reduction in the consumption of foods with a high flatulence index is frequently recommended.

Analysis

As with many concerns about food safety, there is a mixture of accurate and misinterpreted information about pulse toxicity. A prominent example of the dissemmination of misinformation is the "Paleo Diet" which proposes the elimination of pulses and other grains based on their content of anti-nutrients, particularly lectins. However, a careful reading of the scientific literature indicates that properly soaked and cooked pulses are safe to consume because lectins and trypsin inhibitors are inactivated and do not have biological activity. Nonetheless, guidelines available for soaking and cooking are variable and are generally not specific for pulse type, market class, or variety within market class. Moreover, it does not appear that preparation conditions have been validated via published techniques that measure lectin levels and agglutination activity. This is considered an addressable knowledge gap with important practical consequences. In the absence of validated cooking procedures, concerns about pulse safety will be perpetuated. In addressing this knowledge gap, information must be provided in a format that is easily accessed by consumers, food service workers, and those involved in guiding individuals about dietary choices.

Pulse dietary fiber appears to have strong prebiotic effects that improve gut health. As with many carbohydrate rich plant foods, pulse consumption can induce intestinal discomfort and flatulence. However, the extent of these symptoms appears to be influenced in part by heritable factors. This underscores the importance of not presuming that all individuals will experience intolerance when pulses are consumed. In individuals who do report intestinal discomfort and/or flatulence, the symptoms of intolerance are likely to subside after a period of adaptation to increased intake. At this point, the component(s) of pulses that undergo intestinal fermentation is unclear and efforts to reduce symptoms might actually reverse important prebiotics effects that currently are poorly understood. Thus slowly increasing intake of multiple pulse types over a period of several weeks is likely to minimize intolerance and maximize gut health.

Conclusion

For more than 8,000 years most populations of the world benefited from the consumption of one or more pulse crops as an inexpensive source of dietary protein and fiber. Today, pulses continue to offer an affordable, concentrated source of dietary protein and fiber. They are low in fat and have added value because they are gluten and soy free and are non GMO. There is no evidence that properly cooked pulses contain harmful lectins or trypsin inhibitors. Emerging data indicate that for most individuals that intestinal discomfort and flatulence associated with the desirable pre-biotic effects of pulses are transient and unrelated to adverse effects observed when raw or improperly prepared pulses are consumed. This debunks the common myths promulgated by advocates of the “Paleo diet” and opens the door to a practical approach to eliminate the dietary fiber gap while promoting gut health.

Acknowledgments

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Highlights

- Pulses offer an affordable, concentrated source of dietary protein and fiber. They are low in fat and have added value because they are gluten and soy free and are non GMO.
- There is no evidence that properly cooked pulses contain harmful lectins or trypsin inhibitors.
- For most individuals, the intestinal discomfort and flatulence associated with the desirable pre-biotic effects of pulses are transient and unrelated to adverse effects observed when raw or improperly prepared pulses are consumed.
- The common myths promulgated by advocates of the "Paleo diet" are debunked, opening the door to a practical approach to eliminate the dietary fiber gap while promoting gut health.

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Table 1.

Factors impacting pulse safety

Pulse characteristics	Preparation factors	Functional endpoints
Type/variety	Altitude	Target proteins of concern not detected
Age	Soaking duration and temperature	Lack of agglutination activity against relevant targets
Conditions of storage	Cooking temperature/duration	
Cooking type: normal or hard to cook	Use of pressure to cook	

Table 2.

Factors affecting pulse tolerance

Pulse characteristics	Behavioral factors	Physiological factors	Pathological states
Type/variety/ amount/frequency eaten.	Chewing and swallowing habits	Intestinal structure: diameter and folding [a]	Irritable bowel disease
Form ingested: whole seed, mashed, puree, powder	Physical activity/ intestinal transit time	Amount of digestive juice secretion [a]	Diverticular disease
Soaking/Cooking: Soak duration, use of soak water, temperature, pressure	Fluid intake	Composition of gut associated microbiome [a]	Food sensitivities
Storage (cold) after cooking; number of cycles	Bowel habits	Gas metabolism/ ability to reabsorb intestinal gases [a]	Medication use
Other foods ingested with the pulse(s)			

[a]May have a heritible component.