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INVITED REVIEW

Potatoes, Nutrition and Health

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Abstract

Potatoes have been a dietary staple in the US and the world for centuries. Their hardiness, economy and nutrient density render them an invaluable crop. Potatoes contribute key nutrients to the diet including vitamin C, potassium, and dietary fiber. Despite their nutrient density, their impact on human health remains somewhat controversial. Animal studies and some human research indicates that potatoes and potato nutrients may positively impact risk factors for chronic disease including blood pressure, blood lipids and inflammation. Conversely, there observational data linking potato consumption to an increased risk of weight gain and type 2 diabetes purportedly due to the potato's high glycemic index (GI). This review provides an overview of the nutrient content of potatoes as well as a critical evaluation of the existing research examining potatoes and potato nutrients in health and disease states.

Resumen

Las papas han sido un alimento básico en los EU y en el mundo por siglos. Su resistencia, economía y densidad nutritiva la hacen un cultivo invaluable. Las papas contribuyen con nutrientes clave a la dieta, incluyendo vitamina C, potasio y fibra dietética. A pesar de su densidad nutritiva, su impacto en la salud humana permanece de alguna manera controversial. Estudios en animales y algunas investigaciones en humanos indican que las papas y sus nutrientes pudieran impactar positivamente en los factores de riesgo para enfermedades crónicas, incluyendo la presión sanguínea, su contenido de lípidos e inflamación. Por el contrario, hay datos de observación que asocian el consumo de la papa a un riesgo cada vez mayor en aumento de peso y de diabetes tipo 2, supuestamente debido al alto índice glicémico (GI) de la papa. Esta revisión proporciona una vista general del contenido nutricional de las papas, así como una evaluación crítica de la investigación existente que examina la papa y sus nutrientes en situaciones de salud y enfermedad.

Keywords Potatoes · Potato nutrition · Weight loss · Potassium · Vitamin C

Introduction

Potatoes have been a dietary staple in the US and the world for centuries. The potatoes' hardiness made them the ideal crop for the mountainous regions of Peru where fluctuating temperatures, poor soil conditions, and thin air made it nearly impossible to harvest wheat or corn. Today roots and tubers are the third largest carbohydrate food source in the world, with potatoes representing nearly half of all root crops consumed (International Potato Center 2018). Potatoes contribute key nutrients to the diet including vitamin C, potassium, and dietary fiber (McGill et al. 2013). In fact, potatoes have a more favorable overall nutrient-to-price ratio than many other vegetables and are an important staple worldwide (Drewnowski 2013, IPC 2018). However, the impact of potato consumption on human health remains somewhat controversial. Animal studies and limited human clinical trials indicate that potatoes and potato components may positively impact cardiometabolic health (McGill et al. 2013) and some research suggests that they promote satiety (Holt et al. 1995; Geliebter et al. 2013; Akilen et al. 2016). Conversely there is some limited evidence from observational studies linking potato consumption to an increased risk of weight gain and type 2 diabetes purportedly due to their high glycemic index (GI) (Halton et al. 2006; Mozaffarian et al. 2011). This review will provide an overview of the nutritional value of potatoes as well as a critical evaluation of the role of potatoes and potato nutrients in health and disease.

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The nutritional data for the most commonly consumed forms of potatoes are listed in Tables 1 and 2. Note that there are two sets of data for raw (uncooked potatoes) - USDA and FDA. The USDA data are specific to the potato type analyzed, while the FDA data represent a "market-basket" analytic approach, utilizing a weighted average of the nutrients found in potato varieties available to US consumers (USDA 2018). The following paragraphs provide an in depth look at the nutrient content of potatoes.

Macronutrients

Potatoes are classified as "starchy vegetables," highlighting their predominant macronutrient—carbohydrate—and predominant type of carbohydrate—starch. Potato starch consists of amylopectin (branched chain glucose polymer) and amylose (straight chain glucose polymer) in a fairly constant ratio of 3:1 (Woolfe 1987). A small proportion of the starch found in potatoes is "resistant" to enzymatic degradation in the small intestine and, thus, reaches the large intestine essentially intact. This "resistant starch" (RS) is extensively fermented by the microflora in the large intestine producing short chain fatty acids which have been shown to lower the pH of the gut, reduce toxic levels of ammonia in the GI tract, and act as pre-biotics by promoting the growth of beneficial colonic bacteria (Higgins 2004; Brit 2013). Emerging research in animal models and some limited human studies suggests that RS may enhance satiety, positively affect body composition, favorably impact blood lipid and blood glucose levels and increase the amount of good bacteria in the colon (Brit et al. 2013, Gentile et al. 2015, Higgins 2014, Higgins and Brown 2013, Keenan et al. 2015, Robertson 2012, Zhang et al. 2015).

Potatoes contain two of the five subcategories of RS: RS 2 which is found predominantly in raw potatoes and RS3 that is formed when potatoes are cooked and cooled such that the starch gelatinizes and retrogrades (McGill et al. 2013). A recent study examined the amount of RS in three popular potato varieties (Yukon Gold, Red Norland and Russet Burbank) prepared in two different ways (baked and boiled) and served at three different temperatures (hot, chilled for six days, and chilled followed by reheating) (Raatz et al. 2016). The results showed that the RS content of potatoes varied significantly by method of preparation and temperature but not variety. More specifically, regardless of potato variety, baked potatoes had more RS (3.6 g of RS per 100 g of potato) than boiled potatoes (2.4 g of RS per 100 g of potatoes). Also on average, chilled potatoes (whether originally baked or boiled) contained the most RS (4.3 g of RS per 100 g of potato) followed by chilled-and-reheated potatoes (3.5 g of RS per 100 g of potato) and potatoes served hot (3.1 g of RS per 100 g of potato).

Even processed potatoes (e.g., potato flakes) appear to retain a significant amount of resistant starch. Han and colleagues (Han et al. 2008) examined the effects of the consumption of various colored (white, red and purple) potato flakes on cecal fermentation and fecal bile acid excretions in rats. The results indicated that the ingestion of potato flakes was associated with an increase in bowel short-chain fatty acids (SCFA), probably through anaerobic bacterial activities and fermentation of residual starch actions that are helpful for the improvement of the colonic environment.

In addition to RS, potatoes contain dietary fiber—approximately 2 g in a 5.3 oz. potato or 7% of the Daily Value—which is contained both in the flesh and the skin. It is estimated that most Americans get only about half of the recommended amount (i.e., adequate intake (AI)) of dietary fiber and, thus, could benefit from consuming more fiber-rich foods (DGA 2015). A study examining the contribution of white vegetables to nutrient intakes found that white potatoes

Table 1 Energy and macronutrient content of different potato varieties and preparation methods

Potato variety	Serving size	Calories	Total CHO (g)	Fiber (g)	Fat (g)	Protein (g)
Raw Potato+	5.2 oz	110	26	2	0	4
Russet (baked w/skin)*	1 small (138 g)	134	30	3	0	4
Russet (baked w/o skin)*	1 small (138 g)	128	30	2	0	3
Russet (microwaved w/skin)*	1 small (138 g)	145	33	3	0	3
Russet (microwaved w/o skin)*	1 small (138 g)	138	32	2	0	3
Potatoes (boiled in skin)*	1 small 138 g	120	28	2.5	0	2.5
Potatoes (boiled w/o skin)*	1 small 138 g	119	28	2.5	0	2
Red Potatoes (baked w/skin)*	1 small (138 g)	123	27	2.5	0	3
White Potatoes (baked w/skin)*	1 small (138 g)	130	29	3.0	0	3
Potato skin (raw)*	1 skin (38 g)	22	5	1	0	1

*USDA Standard Reference 28

+ FDA nutrition label information (Department of Health and Human Services 2016)

Table 2 Selected micronutrient content of different potato varieties and preparation methods

Potato variety	Serving size	Vit. C (mg)	B1 (mg)	B2 (mg)	B3 (mg)	B6 (mg)	Folate (mcg)	K^+ (mg)	Ca (mg)	Mg (mg)	Fe (mg)	Zn (mg)
Raw Potato+	5.2 oz	27	.12	.03	1.6	.2	24	620	20	33	1.1	0.4
Russet (baked w/skin)*	1 small (138 g)	11.5	.10	.07	1.9	.50	36	759	25	41	1.5	.48
Russet (baked w/o skin)*	1 small (138 g)	18	.14	.03	1.9	.41	12	540	7	34	.5	.40
Russet (microwaved w/skin)*	1 small (138 g)	21	.18	.04	2.4	.48	17	617	15	55	1.7	.76
Russet (microwaved w/o skin)*	1 small (138 g)	21	.18	.03	2.2	.44	17	567	7	34	.57	.46
Potatoes (boiled in skin)*	136 g	18	.15	.03	2.0	.41	14	515	7	30	.43	.41
Potatoes (boiled w/o skin)*	125	9	.12	.02	1.6	.34	11	410	10	25	.39	.34
Red Potatoes (baked w/skin)*	1 small (138 g)	17	.10	.07	2.2	.30	37	752	12	39	1.0	.55
White Potatoes (baked w/skin)*	1 small (138 g)	17	.07	.06	2.1	.30	52	751	14	37	.90	.48
Potato skin (raw)*	1 skin (38 g)	4	.01	.01	0.4	.09	6	157	11	9	1.2	.13

*USDA Standard Reference 28

+ FDA nutrition label information (Department of Health and Human Services 2016)

were positively associated with higher dietary fiber intakes among both children and adults (Storey and Anderson 2013). Specifically, the results indicated, more than 20% of dietary fiber intake was provided by white potatoes for 6 out of 8 age groups for male potato consumers, and > 16% of dietary fiber intake was provided by white potatoes for 6 out of 8 age groups for female potato consumers.

Potato crude protein content is comparable to that of most other root and tuber staples with approximately 2–4 g in a medium potato (depending on the nutrition data utilized as well as the potato variety and preparation methods) (Table 1). It is also comparable on a dry basis to that of cereals and, with the exception of beans, exceeds that of other commonly consumed vegetables (Woolfe 1987; US FDA 2018). Protein quality is often expressed in terms of its "biological value" (BV) which takes into account the amino acid profile of the protein along with its bioavailability. Egg protein has a biological value of 100 and is considered the reference protein. Potatoes have a relatively high BV of 90 compared with other key plant sources of protein (e.g., soybean with a BV of 84 and beans with a BV of 73) (McGill et al. 2013). It is a common misconception that plant proteins are missing or lacking one or more essential amino acid. In fact, potatoes contain all nine essential amino acids and, thus, are a "complete" protein (Woolfe 1987). In fact, a recent study examining the protein and amino acid content of commercially available plant-based protein isolates found that potato protein was superior to other plant-based and was similar to animal-based proteins in terms of essential amino acid content (Gorissen et al. 2018).

Peptides isolated from potato protein (e.g., potato protease inhibitors) have been shown to have antioxidant activity in vitro and some limited evidence from human studies suggests they may have a favorable impact on serum lipids and may enhance satiety (Hill et al. 1990; Kudo et al. 2009; Liyanage et al. 2008). However, it should be emphasized that these peptides are found in relatively low concentrations in the whole potato, and whether the concentrations found in potatoes as consumed are sufficient to produce the effects seen in studies using higher concentrations of isolates remains to be determined.

Micronutrients

Potatoes contain a variety of essential vitamins and minerals (Table 2) most notably vitamins C and B6 and the minerals potassium, magnesium, and iron. A medium (5.2 oz) potato provides 27 mg of vitamin C, qualifying it as an "excellent source" of vitamin C per FDA guidelines. And while potatoes may not rival the vitamin C content (in mg) of citrus fruits and peppers, they do contribute significantly to daily vitamin C requirements. In fact, data indicate that potatoes rank 5th in terms of dietary sources of vitamin C for Americans (Cotton et al. 2004; O'Neil et al. 2012). Potatoes also contain the B vitamins riboflavin, thiamin and folate and are a good source of vitamin B6 (12% of the US daily value per serving). Potassium is a mineral that is under-consumed by the majority of Americans with only 3% meeting their daily requirement (Drewnowski and Rehm 2013; DGA 2015). Potatoes provide one of the most concentrated sources of potassium (Table 2)–significantly more than those foods commonly associated with being high in potassium, such as bananas, oranges, and broccoli (DGA 2015)—and research suggests it is also one of the most affordable vegetables in the National School Lunch Program. (Drewnowski 2013). Magnesium is another nutrient under-consumed by the majority of Americans (Volpe 2013). A medium (5.3 oz) potato with the skin provides 48 mg of magnesium and recent research indicates potatoes contribute 5% of the total magnesium intake in the diets of Americans (Freedman and Keast 2011). And, while the iron content of potatoes is not particularly high (1.3 mg or 6% of the US daily value), the bioavailability of iron in potatoes exceeds that of many other iron-rich vegetables owing to extremely low or non-existent levels of antinutrients, chelators and ligands that inhibit iron absorption (e.g., tannins, oxalates, phytates) and high levels of vitamin C, which has been shown to enhance iron absorption. (Woolfe 1987).

A common misconception when it comes to potato nutrition is that all of the nutrients are found in the skin. While the skin does contain approximately half of the total dietary fiber, the majority (> 50%) of the nutrients are found in the flesh (Table 2). As is true for most vegetables, processing and preparation methods do impact the bioavailability of certain nutrients in the potato, particularly water soluble vitamins and minerals. Nutrient loss appears to be greatest when cooking involves water (e.g., boiling) and/or extended periods of time at high temperatures (e.g., baking) (Table 2) (Bethke and Janksy 2008; Woolfe 1987). Vitamin C is probably most impacted since it is not only water soluble but, also, heat and oxygen labile (McGill et al. 2013; Liu 2013) (Table 1).

Phytonutrients

Potatoes also contain a variety of phytonutrients, most notably carotenoids and phenolic acids (Brown et al. 2005, Liu et al. 2013, McGill 2013) and are the largest contributor of vegetable phenolics to the American diet (Song et al. 2010). Carotenoids, such as lutein, zeaxanthin, and violaxanthin, are found mostly in yellow and red potatoes, although small amounts are also found in white potatoes (Brown et al. 2005). Total carotenoid content of potatoes ranges widely from 35 μg to 795 μg per 100 g fresh weight. Dark yellow cultivars contain approximately 10 times more total carotenoid than white-flesh cultivars (Brown 2008). Anthocyanins are phenolic compounds that are widely distributed among flowers, fruits and vegetables and impart colors ranging from shades of red to crimson and blue to purple (Hou 2003; Liu 2013). The anthocyanins in greatest amounts in potatoes include acylated petunidin glycosides (purple potatoes) and acylated pelargonidin glycosides (red and purple potatoes) (Brown et al. 2005). Chlorogenic acid, a colorless polyphenolic compound, is a secondary plant metabolite and constitutes up to 80% of the total phenolic content of potato tubers (Brown 2005). It is distributed mostly between the cortex and the skin (peel). Finally, quercitin is a flavonoid found in highest amounts in red and russet potatoes (Brown 2005) and has demonstrated antioxidant and anti-inflammatory properties in vitro and in vivo (Kawabata et al. 2015). Further research is needed to determine what role, if any these compounds, may play in mitigating inflammatory responses in humans.

Glycoalkaloids are produced in potatoes during germination and serve to protect the tuber from pathogens, insects, parasites and predators (Woolfe 1987; Friedman 2006). The primary glycoalkaloids in domestic potatoes are α-chaconine and α-solanine and are found in the highest levels in the outer layers of the potato skins (i.e., the periderm, cortex, and outer phloem) (Friedman 2006). Glycoalkaloid levels can vary greatly in different potato cultivars and may be influenced postharvest by environmental factors such as light mechanical injury, and storage (Friedman 2006). Small potatoes also tend to contain higher levels of glycoalkaloids (per unit weight) than larger ones.

In high concentrations, glycoalkaloids are toxic to humans if ingested. Indeed, a number human case studies have documented illness (most notably gastrointestinal effects such as nausea, vomiting, abdominal cramping and diarrhea) and even death due to ingestion of significant amounts of potato glycoalkaloids. What constitutes a "significant amount" varies by country and whether it is an amount consumed (i.e., milagrams per kilogram body weight) or in the potato itself (miligrams per kilogram of potato fresh weight). In many countries (but not the US), the acceptable level of glycoalkaloids has been set <200 mg/kg of fresh weight (Friedman 2006). Re-examining dietary intakes from various case studies, Morris and Lee (1984) calculated that the toxic doses received were in the range of 2–5 mg/kg of body weight, whereas a fatal dose was around 3–6 mg/kg of body weight. Potential toxicity may also depend on whether the glycoalkaloids are ingested in several small, chronic doses or in larger, acute doses, the later of which seems to be more toxic (Friedman 2006).

Similar to other plant phytonutrients, glycoalkaloids not only have toxic effects but also beneficial effects including cholesterol lowering, anti-inflammatory, antiallergic and antipyretic effects (Friedman 2006). Research also suggests that glycoalkaloids have anti-bacterial and antiproliferative (re: cancer cells) properties in vitro (Friedman 2006), however these effects have not been studied sufficiently in vivo.

All of this information notwithstanding, it bears emphasizing that amounts of glycoalkaloids in potatoes available for human consumption are generally low and removal of sprouts and peeling of the tissue approximately 3–4 mm from the outside before cooking removes nearly all of the glycoalkaloids (Friedman 2006).

Potatoes in the American Diet

Potatoes have been a dietary staple for centuries and currently they are one of the most frequently consumed vegetables by Americans (IPC 2018; US FDA 2018; DGA 2015). Potatoes are not only well-liked, but they are versatile, economical and contribute key nutrients to the American diet (Freedman and Keast 2011; Storey and Anderson 2013).

The *2015–2020 Dietary Guidelines for Americans* identified a number of "shortfall" micronutrients, i.e., vitamins and minerals that are currently consumed in inadequate amounts by Americans. These included, but are not limited to, potassium and fiber (2015 DGA). Research indicates that that potatoes make significant contributions of key shortfall nutrients to diets of Americans (Freedman and Keast 2011, Storey and Anderson 2013). Using NHANES 2003–2006 data, Freedman and Keast (2011) examined the contribution of potatoes 205 to nutrient intakes among children and adolescents. The results indicated that potatoes contributed 10% of daily intake of dietary fiber, vitamin B6, and potassium and 5% or more of thiamin, niacin, vitamin C, vitamin E, vitamin K, phosphorus, magnesium, and copper. Research also suggests that adding potatoes to a meal may improve the overall nutrient quality of the meal. Using data from 4-cycles (2001–08) of the National Health and Nutrition Examination Survey (NHANES), Drewnowski et al. (2011) evaluated the impact of white potato consumption (baked, roasted, or boiled) on energy and nutrient intakes in children and adolescents aged 4–18 yr. Approximately 10,600 lunches and 11,500 dinners were characterized by place (at-home or away from home) and by source of food (e.g., store or school cafeteria). The results indicated meals containing white potatoes had significantly higher amounts of vitamin C, potassium and fiber per 1000 cal than meals that did not contain potatoes.

Storey and Anderson (2013) examined the intake and nutrient contribution of total vegetables, white potatoes and French fries in Americans aged 2 and older, based on national dietary intake survey data from NHANES 2009–2010. Individuals who consumed white potatoes had significantly higher total vegetable and potassium intakes than did non-consumers of potatoes. In addition, the proportion of potassium and dietary fiber contributed by white potatoes was higher than the proportion they contributed to total energy. Among white potato consumers aged 14–18 years, white potatoes provided 23% of dietary fiber and 20% of potassium but only 11% of total energy in the diet.

Potatoes are also economical, providing significantly better nutritional value per dollar than many other raw vegetables (Drewnowski and Rehm 2013). Drewnowski and Rehm (2013) examined the nutrient density per unit cost of the 46 most frequently consumed vegetables as part of the National School Lunch Program (NSLP) and found that potatoes and beans were the least expensive sources of not only potassium but also fiber. Specifically, potassium-rich white potatoes were almost half the cost of most other vegetables, making them more affordable to meet key dietary guidelines for good health.

Potatoes and Potato Nutrients in Health and Disease

Potatoes contain a number of nutrients and nutritional components that may play a role in health promotion and reducing the risk of chronic disease. These nutrients along with research supporting their possible roles in human health are described in the paragraphs below.

Blood Pressure/Hypertension

It is estimated that 29%–32% of American adults suffer from hypertension (depending on the data source) and another 1 in 3 have pre-hypertension (CDC 2018). Research indicates that diets low in sodium and rich in potassium may reduce the risk of hypertension and stroke (Adrogué and Madias 2014; Appel et al. 2006; Seth et al. 2014; Yang et al. 2011; Zhang et al. 2013). Although data from individual clinical trials have been somewhat inconsistent, three meta-analyses of these trials have documented a significant inverse association between potassium intake and blood pressure in both non-hypertensive and hypertensive individuals (Appel et al. 2006). Seth et al. (2014) examined the association between potassium intake and stroke in a cohort of 90,137 post-menopausal women and found that a high potassium intake was associated with a lower risk of all stroke and ischemic stroke, as well as all-cause mortality in older women, particularly those who are not hypertensive (Seth et al. 2014). The US Food and Drug Administration (FDA) has approved a health claim for potassium and blood pressure which states, *"Diets containing foods that are good sources of potassium and low in sodium may reduce the risk of high blood pressure and stroke*" (USDA FDA food labeling 2016).

Given their high potassium and low sodium content, potatoes would seem to be an ideal food to incorporate into a dietary pattern for managing hypertension. Nonetheless, very few studies have specifically examined the role of potatoes in blood pressure regulation and/or hypertension treatment. A recent epidemiological study using data from Harvard's well-known Nurses Health Study I and II and Health Professionals Follow-up Study cohorts concluded that a *"Higher intake of baked, boiled, or mashed potatoes and French fries was independently and prospectively associated with an increased risk of developing hypertension*" (Borgi et al. 2016). However, closer examination of the study results actually shows that the association varied depending on which cohort was used as well as which potato groupings were examined. In some cases the positive association between potato intake and hypertension was seen only in women and in others potato consumption was actually associated with *lower* risk for hypertension in men. Furthermore, while the study recommends substituting non-starchy vegetables for potatoes in order to ameliorate the potential increased risk of hypertension, the results actually indicate this substitution was beneficial only for the two female cohorts. In the male cohort, substituting non-starchy vegetables for potatoes actually increased the risk of hypertension. What's more, substituting potatoes with other starchy vegetables (e.g., peas, lima beans, corn and sweet potatoes) did not reduce the risk of hypertension in any of the cohorts. It should also be emphasized that epidemiological studies of this nature can only show an association, not causation.

In contrast to the above-described epidemiological study, two published human experimental trials indicate that potatoes may favorably impact blood pressure. Nowson et al. (2004) examined the effect on blood pressure of two different self-selected diets: (1) a low sodium, high-potassium diet rich in fruit and vegetables (LNAHK) and (2) a high- calcium diet rich in low-fat dairy foods (HC) with a (3) moderate-sodium, high-potassium, high-calcium diet high in fruits, vegetables and low-fat dairy foods (OD) for four weeks. In order to achieve a higher potassium intake, the subjects on the LNAHK diet and OD diets were given a list of potassium rich foods and instructed "to eat a potato a day." The results indicated both the LNAHK and OD produced statistically significant decreases in blood pressure compared to the HC diet; however, the decrease was greatest in the LNAHK diet. In a more recent study, Vinson et al. (2012) fed purple-pigmented potatoes (Purple Majesty cultivar) to 18 overweight (average BMI of 29), hypertensive adult subjects for four weeks in a cross-over design. Subjects in the experimental group consumed six to eight small (~138 g), microwaved purple potatoes twice daily, while those in the control group did not consume potatoes. The results showed that consumption of purple potatoes produced a statistically significant reduction in diastolic BP by 4 mmHg (4.3% reduction) and also reduced systolic BP by 5 mmHg (3.5% reduction) compared to baseline. There were no significant changes in weight, fasting glucose, serum lipids, or HbA1c during the potato consumption period. It should be noted that this study was conducted in a small sample of hypertensive adults. Additional research with larger, more diverse samples are needed to confirm these results.

Weight Management/Obesity

Overweight and obesity have increased significantly during the last three decades both in the US and globally (Ng et al. 2014; Flegal et al. 2016). Although it is generally accepted that dietary patterns along with other key lifestyle behaviors (e.g., physical activity) are more important than single foods when it comes to obesity and weight management (Dietary Guidelines for Americans 2015), potatoes have been singled out both in research and the popular press as being somehow uniquely obesogenic. In a highly-publicized study, Mozaffarian and colleagues (Mozaffarian et al. 2011) examined the association between specific foods and weight gain in three large cohorts (Nurses Health Study I and II and the Health Professionals Follow-up Study). The results of this prospective observational study indicated that four-year weight gain was significantly associated with the intake of potato chips, potatoes, sugar-sweetened beverages, and unprocessed and processed red meats. It is easy to jump to the conclusion that these foods "caused" weight gain. However, it should be kept in mind that this was an observational study and can only show association not causation. It should also be noted that this study suffered from a number of methodological limitations, most notably the failure to statistically control for energy intake, a major oversight considering that excess energy intake is the primary determinant of weight gain (Bistrian 2011).

A recently published systematic review sought to scientifically summarize the existing research regarding the relationship between potato intake and obesity (Borch et al. 2016). In this review the authors identified five observational studies that investigated the association between intake of potatoes and overweight and obesity. Study durations (i.e., the length of subject follow-up) ranged between 2 and 20 y, and 170,413 subjects were included with BMIs that ranged from normal to obese. Two of the five studies examined showed a positive association with measures of adiposity; however, both studies had moderate risk of bias due to methodological weaknesses. The authors concluded that existing epidemiological research does not provide convincing evidence to suggest an association between intake of potatoes and risks of obesity. More clinical/experimental trials that can test for causality are needed. Nonetheless, there is evidence to suggest that potatoes do not need to be excluded from a weight management diet (Randolph et al. 2014).

Research from single meal studies suggests that boiled potatoes are more satiating than equal calorie portions of other common carbohydrate-rich foods (e.g. rice, bread and pasta) (Holt et al. 1995; Leeman et al. 2008; Geliebter et al. 2013). However subjective measures of satiety do not always correlate with energy intake or changes in body weight. In the only long-term intervention study to date to examine the specific role of potatoes in weight management, Randolph and colleagues (Randolph et al. 2014) studied the effects of potato consumption on weight loss in free living adults**.** In a 12-week, 3-arm, randomized control trial, 90 overweight men and women were randomly assigned to one of three dietary interventions: (1) low GI, calorie reduced diet (500 kcal/d); (2) high GI, calorie reduced diet (500 kcal/d); (3) control group (counseled to follow basic dietary guidance including the Dietary Guidelines for Americans and the Food Guide Pyramid). All three groups were instructed to consume five-to-seven servings of potatoes per week (approximately one potato per day) and were provided with a variety of recipes for potato dishes. Modest weight loss was observed in all three groups (~2% of initial body weight) with no significant difference in weight loss between the groups, likely due to the fact that the "control" group spuriously reduced their energy intake to levels on par with the two intervention groups. Additional research, particularly clinical trials are needed to address the role of potatoes in weight management.

Glycemic Response/Type 2 Diabetes

Because of their carbohydrate content and supposed high glycemic index (GI), potatoes are not only frequently restricted in diabetic dietary guidance, but are also implicated in the development of the disease (Halton et al. 2006). While there is some limited epidemiological evidence suggesting an association between high GI foods, including potatoes, and diabetes, there are no clinical/experimental trials demonstrating cause and effect. Halton and colleagues (Halton et al. 2006) prospectively examined the association between potato consumption and risk of diabetes in a large cohort of women (i.e., the Nurses Health Study) who were followed for 20 years. The authors concluded that potatoes (including baked, boiled, mashed and French fries) were positively associated with risk of type 2 diabetes and cite the GI of potatoes as the likely mechanism for the increased risk. In fact, a closer look at the results of the study shows that once BMI was included in the statistical model and controlled as a cofactor the association no longer remained significant for baked, boiled or mashed potatoes (Halton et al. 2006); only French fries remained significant. Controlling for BMI is important because overweight/obesity is the primary risk factor for type 2 diabetes (NIDDK website https://www.niddk.nih.gov/health-information/diabetes/overview/risk-factors-type-2-diabetes). It should also be noted that the authors did not control for other dietary factors that could account for the association, specifically red meats. In the discussion section of the paper, the authors themselves admit to this statistical faux pas, "White potatoes and French fries are large components of a 'Western pattern' diet. This dietary pattern is characterized by a high consumption of red meat, refined grains, processed meat, high-fat dairy products, desserts, high-sugar drinks, and eggs, as well as French fries and potatoes. A Western pattern diet previously predicted a risk of type 2 diabetes. Thus, we cannot completely separate the effects of potatoes and French fries from the effects of the overall Western dietary pattern" (Halton et al. 2006). Finally, the hypothesized mechanism for the association (i.e., the "high GI" of potatoes) is unfounded. In fact, the GI of potatoes is highly variable and depends upon the type, processing and preparation. In a study examining the GI of potatoes commonly consumed in North America, GI values ranged from intermediate (boiled red potatoes consumed cold: 56) to moderately high (baked US Russet potatoes: 77) to high (instant mashed potatoes: 88; boiled red potatoes: 89) (Fernandes et al. 2005). Another study examined the GI of eight varieties of commercially available potatoes in Great Britain and reported a range from 56 to 94 (Henry et al. 2005). French fries are reported to have a GI lower than boiled potatoes (Leeman et al. 2008).

There are currently no published clinical trials examining potato consumption as a causative factor in development of diabetes. A recent systematic review of the existing observational studies identified five which showed a positive association between potato consumption and increased risk of type 2 diabetes (including the previously mentioned study by Halton and colleagues), five showed no association and two actually showed that potatoes were associated with a decreased risk (Borch et al. 2016). Again, it should be emphasized that observational studies cannot show cause and effect, only an association. Moreover, it is difficult to tease out the effects of single foods from larger dietary patterns and make any definitive conclusions relative to the risk of type 2 diabetes. Thus, randomized controlled intervention trials investigating the relationship between potatoes and type 2 diabetes are needed to separate potato consumption from other known risk factors.

Gut Health

While there is currently no official definition of "gut health," in an article published in the peer-reviewed journal, *Biomed Central Medicine*, Bischoff listed some specific signs of gastrointestinal (GI) health, including normal bowel function, effective absorption of nutrients and subsequent adequate nutritional status, absence of GI illnesses, normal and stable intestinal microbiota and effective immune status (Bischoff 2011). Potatoes contain a number of nutritional components which may play a role in supporting "gut health" as defined by Bischoff, most notably fiber and RS; however, the research is still based largely on animal and in vitro studies. As previously mentioned, both fiber and resistant starch escape digestion in the small intestine and enter the colon where they can provide fecal bulk thus helping to maintain normal bowel function. In addition, results from a systematic review and meta-analysis suggest that some types of RS undergo colonic fermentation and may function as a pre-biotic, supporting the proliferation of the colonic microbiota (Higgins and Brown 2013; Shen et al. 2017).

Finally, potatoes are gluten free, thus they are a key source of nutrient dense carbohydrates in the diets of those with celiac disease and/or gluten sensitivity. According to the National Foundation for Celiac Awareness, an estimated 1 in 133 Americans, or about 1% of the population, suffers from celiac disease and would benefit from reducing or eliminating foods containing gluten. However, eliminating foods with gluten can predispose individuals to nutrient inadequacies. Shepherd and Gibson (2013) examined dietary intakes from 55 men and women who had been following a gluten-free diet for two years and found inadequate intakes of fiber and several micronutrients, including thiamin, folate, magnesium, calcium and iron. Potatoes provide a number of those nutrients and thus are a key food for someone needing or wanting to follow a gluten-free or gluten-restricted diet.

Summary/Conclusion

The potato has been a dietary staple for centuries and remains a popular and frequently consumed vegetable today. Potatoes contribute important nutrients to the diet including potassium, vitamin C and dietary fiber. Observational data indicate that potato consumption is associated with an increase in overall vegetable consumption and dietary nutrient density among children, teens and adults in the United States. Research suggests that potato nutrients and components may have favorable impacts on blood pressure, satiety and 412 gut health; however, data from observational studies examining the effects of consuming whole potatoes on body weight and disease risk remain controversial. There is currently a lack of experimental data regarding the impact of potato consumption on obesity, weight management and/or diabetes; thus, randomized controlled intervention trials investigating the effect of potato consumption on various health outcomes and disease states are needed to better isolate potato consumption from other known risk factors. Until then, dietary guidance should continue to stress the importance of healthy eating patterns that consist of a variety of vegetables, including nutrient dense potatoes.

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