Imran S *et al.* (2025)
Notulae Botanicae Horti Agrobotanici Cluj-Napoca
Volume 53, Issue 1, Article number 14080
DOI:10.15835/nbha53114080
Review Article

A panoramic review on phytochemistry, pharmacological potential, health benefits, and versatility of *Solanum tuberosum* L.

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Abstract

The potato (*Solanum tuberosum* L.) belongs to the family Solanaceae and is one of most versatile crops, vital components of the human diet in numerous countries. It is regarded as one of the most promising crops for reducing world hunger and poverty. It is one of the foremost non-grain crops in the world, being a cost-effective and easily accessible food with several health benefits. The entire plant including peel, tuber, and leaves are used in traditional medicine. Potatoes are high in carbohydrates, lipids, phenolic acids, anthocyanins, carotenoids, proteins, flavonoids, vitamins, potassium, phosphorus, copper, and fiber. The purpose of this review study was to present up-to-date information on novel metabolites discovered in potatoes that play a role in preventing illness and improve human well-being. We attempted to assemble data on the variety of pharmacological activity including antioxidant, anti-diabetic, antihypertensive, anticancer, antiobesity and anti-inflammatory properties of potatoes, as well as their function in enhancing gut health and satiety. *In-vitro* investigations, human cell culture, experimental animal studies have revealed that potatoes have a variety of health-promoting qualities. The observations and recommendations presented here are scientifically interesting for food chemistry, pharmacology, nanotechnology, and toxicology. These may also contribute to enhance nutrition, food safety, and human health.

Keywords: anticancer; anti-obesity; antioxidant; food; nanoparticles; potato

Received: 22 Aug 2024. Received in revised form: 14 Oct 2024. Accepted: 29 Nov 2024. Published online: 27 Feb 2025.
From Volume 49, Issue 1, 2021, Notulae Botanicae Horti Agrobotanici Cluj-Napoca journal uses article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

Introduction

The potato (*Solanum tuberosum* L.) has been an important food source for human populations for hundreds of years (Beals, 2019). In nineteenth-century Europe, the starter of the potato from the New World also made a substantial contribution to the Industrial Revolution. The potato was an important food crop because it helped small farmers. After wheat and rice, potatoes are currently the third-largest food crop worldwide (Jansky *et al.*, 2019). About 15% of the world's population gets their energy from the potato, which is a widely grown commercial crop and the most common food crop (Karim *et al.*, 2016). On the other hand, particularly in United States and in the highlands of American countries, adults consume 5-6 times the amount of potato consumed in developed countries. In 2018, China ranked first in potato production, accounting for approximately 24.53% of global output (Li *et al.*, 2023). Worldwide, a lot of people consume potato (*Solanum tuberosum* L.) tubers because they are high in fiber, energy, protein, and vitamins, among other nutrients, and low in fats (Ercoli *et al.*, 2021). Additionally, potatoes are inexpensive and available all year round. It is mostly used as a source of carbohydrates when taken as food. However, there is still much to understand about potato nutrients and human health (Jansky *et al.*, 2019). Usually, potatoes are used to create well-known consumer goods such mashed potatoes snack food and potato chips (Li *et al.*, 2018; Yang *et al.*, 2021; Dong *et al.*, 2024).

The *Solanum tuberosum* L. is a tuberous, starchy, and perennial plant of the family Solanaceae (also known as the nightshades), which is well known for its economic and ecological significance (Aksoy *et al.*, 2021). Its taxonomy can be quite complex due to the numerous species and varieties. The cultivated potato commonly found in diets is *Solanum tuberosum* L. Approximately 200 different potato varieties exist, and they are divided into several groups based on how they cook and how well they work as an ingredient. A deep convolutional neural network was trained to distinguish four different types of potatoes (red, red washed, purple sweet, and white) using a publicly available dataset of 2400 photos of potatoes (Elsharif *et al.*, 2020; Li *et al.*, 2024; Zhang *et al.*, 2024).

The carbohydrate-rich meal potato, together with a small amount of fat, gives a person 130 kcal of daily energy. This nutritious vegetable contains numerous vitamins, polyphenols (0.0071-0.031%), crude fibers (0.6-0.8%), proteins (1.5-2.3%), starch (9-20%) (Ezekiel *et al.*, 2013). The presence of carotenoids and anthocyanins in potatoes causes them to come in a variety of colors, although the genotypes with no color are the most prevalent (Rasheed *et al.*, 2022). The flesh and peel of potatoes include several bioactive substances like polyphenols, anthocyanins, and carotenoids that have been intensively studied, giving the tubers considerable significance. (Tian, *et al.*, 2022). Among the most widely consumed vegetables, potatoes demonstrated excellent antioxidant capacity. In terms of hydrophilic antioxidant capacity, the Russet potato, one of the most popular kinds in North America, comes in second only to broccoli in terms of antioxidant content. As a staple crop, potatoes are ideally suited to provide these antioxidant phytochemicals, and new research on colored potatoes with high anthocyanin and carotene concentrations has increased interest in potatoes' ability to promote health (Tsao, 2009). Numerous investigations have reported that, because of its antioxidant (Kowalczewski *et al.*, 2012) analgesic, anti-inflammatory (Wahyudi *et al.*, 2020), anticancer/antitumor (Vanamala, 2019) and antiulcer properties, potatoes have been shown to usually be helpful in the prevention or treatment of chronic diseases. The tubers are also used as anti-gout, anti-arthritic, anti-scurvy, and diuretic and to increase milk production in lactating mothers (Gnanasekaran and Basalingappa, 2018).

Potatoes are storable, inexpensive, thrive in a variety of climates, and can provide extremely high yields per acre. As a result, potatoes can contribute to raising agricultural output to meet the estimated increase in demand required by 2050 to assure global food security. Furthermore, specialized baby potatoes, particularly color-flesh varieties, may appeal to consumers looking to increase their phytonutrient consumption or discover new food (Valcarce Navarre *et al.*, 2019). Most studies have focused on the nutritional components of potatoes, including carotenoids, phenolics, anthocyanins, vitamins, proteins, and minerals. In recent years, a limited number of studies have examined the invitro bio accessibility of these substances (Mishra *et al.*, 2020; Raigond *et al.*, 2023). Potatoes contain a wide range of health-promoting compounds that play significant roles in disease prevention. Most research has concentrated on the presence of these compounds in colorful potatoes, while fewer studies have explored the presence of several health-promoting compounds in regular cream-yellow fleshed potatoes. This review offers a comprehensive synthesis of potatoes as nutrient-rich foods and sources of bioactive phytochemicals. It highlights their nutritional value, health benefits in raw and processed forms, therapeutic potential, and explores the commercial applications of potato byproducts for sustainable use.

Contribution to Diet

Dietary fiber

The *Solanum tuberosum* L., is a plant that is well-known for its nutritional benefits as a large source of protein, dietary fiber, and carbohydrate. As the fourth most important food crop worldwide, potatoes offer two major types of dietary fiber: water-insoluble dietary fiber (IDF) and water-soluble dietary fiber (SDF). SDF is known for its favorable physiological effects and primarily serves roles such as cholesterol reduction, blood sugar level regulation, lowering the threat of cardiovascular and cerebrovascular. Key constituents of SDF include glucan, pectin, soluble arabxylan and xylo-oligosaccharide (Shen *et al.*, 2020). Given SDF's heightened physiological significance compared to IDF, there's a growing focus on researching efficient and secure methods to transform IDF into SDF, making it a prominent research area. An average daily intake of 18 g/day of SDF for the purpose of reducing fasting blood glucose levels is required (Ma *et al.*, 2022). Insoluble dietary fiber (IDF) encourages the mechanical movement of intestinal contents, which helps to regulate intestinal function, avoid constipation, and maintain the health of the large intestine. IDF's main ingredients are cellulose, hemicellulose, and lignin (Zhang *et al.*, 2023). Potatoes have historically served as a primary starch source, and in China, sweet potatoes were responsible for approximately 33% of the starch supplied to various industries (Liu *et al.*, 2020). Because potatoes are frequently thought of as high-carb, calorie-dense meals with large fat content, possess significant health-promoting qualities are frequently underestimated by the public (Singh *et al.*, 2020; Luo *et al.*, 2021; Gao *et al.*, 2022).

Carbohydrates

The primary carbohydrate in potatoes is starch, which is composed of amylose and amylopectin. Amylose consists of linear chains of glucose linked by α-1,4 glycosidic bonds, while amylopectin is a branched polymer containing both α-1,4 and α-1,6 linkages. These two forms determine the starch granule structure and its digestibility. Starch in potatoes can be classified into three types: rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS) (Sawicka and Gupta, 2018). RDS, which is digested within 20 to 120 minutes of ingestion, causes rapid increases in blood glucose levels, whereas SDS, despite being fully digested in the small intestine, supports stable blood glucose levels due to its slow absorption (Ulmius *et al.*, 2012). Resistant starch, found in raw or processed potatoes, remains undigested in the small intestine but undergoes fermentation in the large intestine, producing short-chain fatty acids that promote gut health (Venn and Green, 2007; Zhang *et al.*, 2023; Ban *et al.*, 2024).

<u>Resistant starch</u>

Some potatoes contain resistant starch, a kind of carbohydrate that resists digestion in the small intestine and reaches the colon, where it can be fermented by gut bacteria. Metabolomics can help identify the metabolites produced during this fermentation process, offering insights into the potential benefits of resistant starch on health of gut and the production of short-chain fatty acids, which may have health-promoting effects (Birt *et al.*, 2013).

Potatoes starch contains some resistant starch, which acts like dietary fiber in the body. It can help improve digestive health and may have a positive impact on blood sugar control. Resistant starch (RS) is useful to humans, particularly those with diabetes. Raw potato contained a high concentration of RS, the majority of which became digestible afterwards gelatinization. As such, just a small amount of RS remains in potatoes after normal cooking (Peng *et al*., 2022). Potatoes include two of the five RS subcategories: RS 2 (found primarily in raw potatoes) and RS 3 (produced after potatoes are cooked and chilled, causing the starch to gelatinize and retrograde). RS is classified into RS1, RS2, RS3, RS4 and RS5, Permitting to the mechanism of its enzymatic resistance. According to Liu *et al*., 2020 raw potatoes are a natural source of RS and contain between 47 and 59% of it in their dry mass. However, RS2—which typically takes the form of a B- or C-type polymorph—makes up the majority of RS in raw potatoes and is greatly digestible after gelatinization (Liu *et al.,* 2020; Robertson *et al*., 2020).

Several studies concluded that Certain kinds of resistant starch (RS) have been linked to enhanced whole-body insulin sensitivity. It is also suggested that RS-enriched potatoes may have a favorable impact on carbohydrate metabolism (Sanders *et al*., 2021). Resistance starch contains absorptive and digesting qualities that may be beneficial to health. Dietary RS is distinct in that it does not disintegrate as quickly as regular starch and has significant health benefits, some of which are like those offered by dietary fiber and others of which are specific to RS (Raatz *et al*., 2016). Increased satiety, higher insulin sensitivity, improved glycemic management, and improved gut health are among the physiological effects of RS that have been scientifically proven (Keenan *et al*., 2015).

Lipids

Potato lipids are relatively low, ranging from 0.1 to 0.5 g/100 g fresh weight (FW), primarily consisting of phospholipids (47%), glycol and galactolipids (22%), which play crucial roles as structural components in biological membranes, and neutral lipids (21%), including acylglycerols and free fatty acids, which serve as an energy storage and source in the potato. These lipid components collectively contribute to the functionality and stability of cell membranes in potatoes while also providing a limited energy reserve in the form of neutral lipids (Ramadan and Oraby, 2016) On the other hand, the intake of 4% saturated fatty acids and 6% trans fatty acids in potato dishes is primarily due to the incorporation of oils and fats like margarine and butter into the recipes. This addition of saturated and trans fats can significantly raise the overall fat content and, consequently, increase the health concerns associated with potato-based meals, as excessive consumption of these fats is known to be linked to various cardiovascular and health risks (Burgos *et al*., 2020). The fatty acid content of potato lipids is nutritionally beneficial. For instance, in the United Kingdom, potato consumption is projected to provide approximately 10% of dietary n-6 polyunsaturated fatty acids and approximately 13% of dietary n-3 polyunsaturated fatty acids (Gibson and Kurilich, 2013). The potato's total lipid content ranges between 0.15% and 0.5% of its fresh weight. Potato lipids are high in linoleic and linolenic acids. It may contain bioactive lipid components such as phospholipids, sterols, glycolipids, and carotenoids, which are more desired because of their health-promoting properties (Lal *et al*., 2020; Ji *et al*., 2023).

Proteins

There are many amino acids in potato protein that have hydrophobic functional groups, particularly branched including isoleucine, leucine, and valine along with the aromatic amino acids, phenylalanine, and tyrosine (Karenlampi and White, 2009). The proportion of different amino acids methionine, lysine, tryptophan, and threonine, in varied meals ingested by humans are likely to reduce the protein. Potatoes contain more of these essential amino acids than is required, indicating that potato protein is of excellent quality (Table 2). Potato protein has a high biological value as it contains all of the essential amino acids in good proportions. Potato protein serves as an excellent emulsifier and stabilizer in food applications. Red and purple potato cultivars have been reported to contain higher protein levels than yellow and cream-fleshed varieties, indicating varietal differences in nutrient content (Głosek-Sobieraj *et al.*, 2022).

Minerals

Potato tubers are known for their relatively high potassium content. A study reported that high yielding, medium-sized potato (about 200 grams) can contain anywhere from 720-850 milligrams of potassium. This is representing 18% of the recommended dietary reference intake for potassium is 4,700 mg for adults (see Table 1) (White *et al.*, 2009). Potassium is essential for maintaining proper muscle function, regulating blood pressure, and supporting overall cardiovascular health. Potassium can lower the risk of stroke, blood pressure, kidney stones, heart disease, and support normal cardiac rhythms. A recent study found that a lack of potassium is linked to artery stiffening (Sun *et al.*, 2017). Potatoes contain phosphorus and magnesium in moderate amounts, with phosphorus levels ranging from 42 to 120 mg/100 g fresh weight (FW) and magnesium levels ranging from 16 to 40 mg/100 g FW. These minerals are important for various physiological functions in the body, including bone health and energy metabolism. In children the P requirements go from 400 to 700 mg/day, in adolescents is about 1 gr/day while in adult the daily average requirement is in the range 600-700. The calcium content in potatoes typically falls within the range of 2-20 mg per 100 grams of fresh weight (FW). Consuming potatoes can provide a relatively small amount of calcium, contributing a little more than 2% of the Estimated Average Requirement (EAR) for calcium in adults. The recommended daily intake of calcium for adults usually ranges from 800 to 1000 mg per day, depending on individual factors (Bonierbale *et al.*, 2010). In cooked potatoes, the concentrations of zinc range from 0.29 to 0.48 mg per 100 grams of fresh weight (FW), and the concentrations of iron range from 0.29 to 0.69 mg per 100 grams of fresh weight (FW) (Burgos *et al.*, 2007). Potatoes are a significant nutritional supply of iron. In the Andean highlands, there is minimal availability of meat and a high incidence of malnutrition and anemia. Women and children in Huancavelica, Peru's highlands, consume varying amounts of potatoes, ranging from 200 to 840 grams per day, reflecting the importance of potatoes as a staple food in their diet (De Haan *et al.*, 2019). Potatoes, due to their high potassium and low salt content, appear to be a suitable food to integrate into a hypertension-management diet. Despite this, only a few research has specifically looked at the effect of potatoes in management of blood pressure and hypertension. According to a recent epidemiological study that utilized data from Harvard's renowned Nurses' Health Study I and II, as well as the Health Professionals Follow-up Study cohorts, "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).

Table 1. The mineral content of 200 g fresh weight of potatoes and its contribution to the U.S. Dietary Reference Intake (DRI)

Mineral	DRI	US potatoes	UK potatoes	DRI Percent
K(mg)	4700	850	720	18
P(mg)	700	118	74	17
Mg(mg)	420	45	34	11
Ca(mg)	1000	22	10	2.2
Cl(mg)	2300	-	132	-
N(mg)	NS	-	660	-
S(mg)	NS	-	60	-
Na(mg)	1500	12	14	0.8
Fe(mg)	8	1.4	0.8	18
Zn(mg)	11	0.6	0.6	5.51
Mn(mg)	2.3	0.3	0.2	13
Cu (µg)	900	231	160	26
I (µg)	150	37	6	25
Se (µg)	55	0.8	2	1.4

Mineral contents are means of different high yielding cultivar in UK and US (Unspecified verities, skin flesh) White *et al.*, 2009. The DRI are those for a 31-50-year-old male (National Academy of science 2004). NS= Not specified

Vitamins

Potatoes are definitely a good source of ascorbic acid, which is also known as vitamin C, and pyridoxine, which is vitamin B6 (Mushinskiy *et al.*, 2021). Vitamin C, is an antioxidant that helps boost the immune system, promote healthy skin, and support wound healing. Scurvy is caused by a lack of vitamin C, which causes a failing of blood vessels, connective tissues bones, hair, and teeth, then joint inflammation, and eventually death. Potatoes are a key source of vitamin C around the world, accounting for about 20% of dietary consumption in Europe (Table 2). They are the basis of vitamin C not only because of their high concentration, but also because they can be kept, resulting in consistent availability. Any increases in the vitamin C content of potato products will benefit human nutrition (Love and Pavek, 2008). According to Valcarcel *et al.* (2015), the levels of vitamin C in potato flesh, ranging from 798 to 117 mg/kg, are directly proportional to the production of L-galactono-1,4-lactone dehydrogenase, which is an enzyme involved in the pathway for vitamin C (l-ascorbate) biosynthesis in plants. This means that as the production of this enzyme increases, there is a corresponding increase in the levels of vitamin C in the potato flesh. This relationship reflects the importance of this enzymatic pathway in the biosynthesis of vitamin C in potatoes (Valcarcel *et al.*, 2015). Potato has significant quantities of ascorbic acid, which is known to improve iron absorption (Burgos *et al.*, 2020). Potatoes are also good source of vitamin B6, with concentrations typically ranging from 0.450 to 0.675 mg per 100 grams of fresh weight (FW). Vitamin B6, also known as pyridoxine, plays a crucial role in various metabolic processes in the body, including the metabolism of amino acids and the production of neurotransmitters. Consuming potatoes can contribute to meeting your dietary vitamin B6 requirements (Mooney *et al.*, 2013). In comparison to other staple foods, cooked potatoes have a higher mean concentration of vitamin B6, with approximately 0.299 mg per 100 grams of fresh weight (FW). This is significantly higher than the vitamin B6 content found in maize (0.139 mg/100 g FW), cassava (0.051 mg/100 g FW), rice (0.050 mg/100 g FW), and wheat (0.034 mg/100 g FW) (Fudge *et al.*, 2017). The potato tuber also comprises an adequate level of vitamin E. Vitamin E refers to a group of eight related tocopherols and tocotrienols (Chitchumroonchokchai *et al.*, 2017).

Table 2. Potatoes' proximate composition and nutritive value per 100 g

Nutritional composition	Amount	Unit	References
Moisture content	3.36-5.66	Mg	Burgos *et al.*, 2020; Borgi *et al.*, 2016; Burlingame *et al.*, 2009
Energy	96-123	Kcal	Burgos *et al.*, 2020; Burlingame *et al.*, 2009
Carbohydrate (Starch)	16-20	G	Robertson *et al.*, 2020; Furrer *et al.*, 2018
Ash	6.69-9.31	Mg	Burgos *et al.*, 2020
Protein	1.76-2.94	G	Robertson *et al.*, 2020; Mushinskiy *et al.*, 2021; Furrer *et al.*, 2018
Lipids	0.1-0.5	G	Ramadan and Oraby, 2016
Dietary Fibers	1.8-2.1	G	King and Slavin, 2013
Potassium	150-1386	Mg	Nassar *et al.*, 2012
Vitamin C	7.8 -20.6	Mg	Burgos *et al.*, 2020
Phosphorus	42-120	Mg	Bonierbale *et al.*, 2010
Zinc	0.29-0.48	Mg	Gibson and Kurilich, 2013; Wijesinha-Bettoni and Mouille, 2019
Magnesium	16-40	Mg	Wijesinha-Bettoni and Mouille, 2019
Iron	0.29-0.69	Mg	Wijesinha-Bettoni and Mouille, 2019
Vitamin B6	0.299	Mg	Furrer *et al.*, 2018
Chlorogenic acid	3-90	Mg	Ezekiel *et al.*, 2013; Visvanathan *et al.*, 2016

Glycoalkaloids	3-20	mg	Lister and Munro, 2000; Bradshaw, 2019; Visvanathan *et al.*, 2016
Anthocyanins	5.5-35	Mg	Camire *et al.*, 2009; Visvanathan *et al.*, 2016

Phytochemicals

Potatoes are rich in health-promoting substances that contribute significantly to their role in dietary phytochemistry. Studies have found that potatoes exhibit higher antioxidant activity compared to other vegetables, such as carrots, bell peppers, and onions, primarily due to their phenolic content (Blessington *et al.*, 2010). The key hydrophilic antioxidants in potatoes include polyphenols, ascorbic acid, anthocyanins, and flavanols. Yellow-fleshed potatoes derive their antioxidant activity mainly from chlorogenic acids, caffeic acid, gallic acid, and catechin, while anthocyanins and chlorogenic acids contribute to the antioxidant properties of pigmented potatoes (Figure 1). Chlorogenic acid, the most prevalent polyphenol in potatoes, plays a critical role in preventing lipid oxidation (Burgos *et al.*, 2013).

The antioxidant components in potatoes serve multiple functions, including scavenging superoxide radicals, chelating ferrous ions, neutralizing free radicals, and breaking down lipid peroxides. Polyphenolic substances are significant contributors to the antioxidant potential of potatoes and their extracts (Camire *et al.*, 2009). Purple-fleshed potatoes, known for their higher polyphenol content, exhibit superior antioxidant capacity due to the presence of anthocyanins and petunidin derivatives (Ercoli *et al.,* 2021). In contrast, yellow and white potatoes have lower total phenolic content (TPC), leading to reduced antioxidant properties (Ru *et al.,* 2019).

Phenolic compounds in potatoes also provide a variety of health benefits beyond antioxidant activity. They exhibit antibacterial, antidiabetic, anti-inflammatory, antiviral, anti-cancer, and vasodilatory properties (Mattila and Hellstrom, 2007). Phenolic acids such as chlorogenic, ferulic, caffeic, and sinapic acids are particularly abundant. Anthocyanins, responsible for the red-blue pigmentation in some potato varieties, not only affect the sensory properties of foods but also offer potential health benefits by influencing food processing behaviors (de Pascual-Teresa and Sanchez-Ballesta, 2008). Potatoes contain three isomers of chlorogenic acid, including 5-O-caffeoylquinic acid, which supports gut health by promoting the growth of beneficial Bifidobacterium species (Mills *et al.,* 2015). Chlorogenic acid is the most abundant phenolic acid in both raw and boiled potatoes, highlighting its dietary relevance (Li *et al.*, 2018).

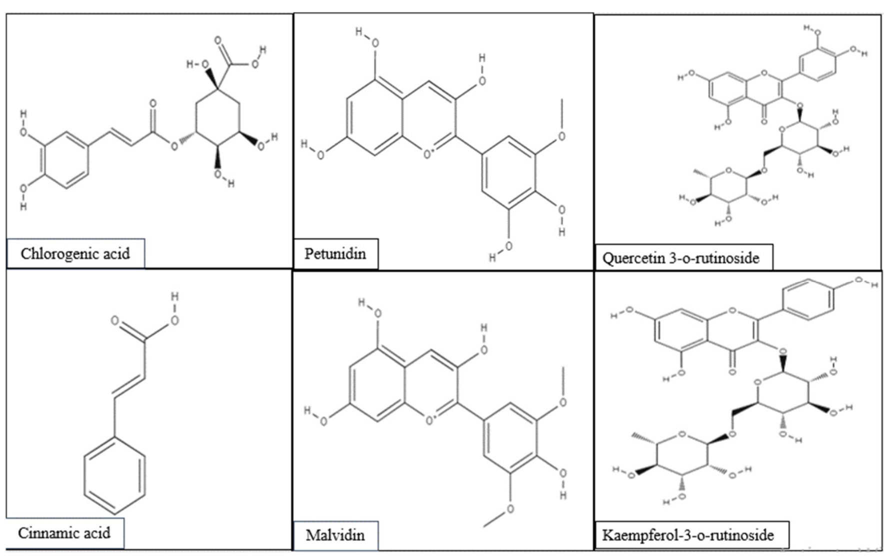


Figure 1. Structure of some phytochemicals (phenols, flavanols, anthocyanins) have been isolated from potatoes

Flavonols, although present in small quantities in potato tubers, further enrich the phytochemical profile. Trace amounts of flavonols like rutin and kaempferol are found in potatoes, with levels ranging from 0 to 4.78 mg/100 g FW for rutin and from 0 to 5.68 mg/100 g FW for kaempferol-3-O-rutinoside in Andean varieties (Andre *et al*., 2007). The production of flavonols is influenced by environmental factors, with light-exposed potatoes accumulating more flavonols than those stored in darkness. Cold storage also increases the levels of both flavonols and anthocyanins in tubers (Schulz *et al*., 2016).

Pigmented potatoes contain anthocyanins acylated with caffeic, p-coumaric, and ferulic acids, which enhance their antioxidant capacity (Giusti *et al*., 2014). Raw and cooked purple-fleshed potatoes contain anthocyanin concentrations ranging from 63 to 588 mg/100 g FW and 71 to 453 mg/100 g FW, respectively. In contrast, cooked red-fleshed potatoes have lower anthocyanin levels, ranging from 8.2 to 55.3 mg/100 g FW (Burgos, 2014).

Additionally, potatoes are a source of carotenoids, which are lipophilic phytonutrients with numerous health-promoting effects, including reducing the risk of chronic diseases (Wu *et al.,* 2015). The bioavailability of carotenoids from potatoes depends on factors such as their molecular structure, release from the food matrix, intestinal absorption, transport within lipoproteins, and the nutritional status of the consumer (Bohn, 2017). While the presence of carotenoids in potatoes offers significant health benefits, further research is needed to better understand their bioavailability and physiological impact.

Glycoalkaloids

Potatoes and other Solanaceae members contain nitrogenous substances called glycoalkaloids. Potatoes include the glycoalkaloids such as α -chaconine and α -solanine as their main components. These chemicals are localized in the skin and have varying ratios (Table 2). The steroidal glycoalkaloids found in the Liliaceae and Solanaceae families have historically been referred to as "glycoalkaloids." These substances are currently sometimes referred to as Solanum glycoalkaloids (SGA) or potato glycoalkaloids (PGA), but this terminology is not widely used. Over 300 Solanum species have yielded at minimum 90 structurally distinct steroidal alkaloids, which have been isolated and categorized (Friedman *et al*., 1997). Glycoalkaloids are nitrogen-rich secondary plant metabolites present in a wide variety of Solanaceae plants, such as potatoes, tomatoes, and eggplant (Al Sinani and Eltayeb, 2017) When subjected to the glycoalkaloids (α -chaconine and α -solanine) and their hydrolysis product produced by potatoes, the cancer cells are inhibited from growing both in vitro (in a culture dish) and in vivo (in a tumor) (Freidman, 2015). Glycoalkaloids are harmful to humans when consumed in large quantities. In fact, several human case studies have shown that ingesting large doses of potato glycoalkaloids can cause disease (particularly gastrointestinal tract symptoms like nausea, abdominal cramping, and diarrhea) and eventually death (Beals, 2019). According to Friedman (2006), glycoalkaloids have both detrimental and advantageous effects, such as decreasing cholesterol and having anti-inflammatory, antiallergenic, and antipyretic properties. Glycoalkaloids may possibly have antibacterial and antiproliferative properties (Friedman *et al*., 2006). Grunenfelder *et al.* (2006) challenged the assumption that green potatoes had greater glycoalkaloids concentrations. Both glycoalkaloids and chlorophyll in the presence of light, assemble in potato skins, although they do so independently. The total glycoalkaloids content (TGA) of new cultivars is evaluated because of concern about the impact of these substances on human health (Brown, 2008). The two main substances in commercial potato cultivars are α -solanine and α -chaconine, which are glycosides of the steroidal alkaloid solanidine. Although there is considerable disagreement over the precise role that these substances play in plants, it has been demonstrated that these and comparable substances have hazardous effects on people. Even within the same cultivar, climatic variances in the growing location might result in significant variations in the glycoalkaloids concentration. Additionally, even after harvest, tubers continue to produce glycoalkaloids, and poor handling and/or storage practices may result in a sharp increase in these substances. Content of glycoalkaloids may also change due to processing. Although the amounts of glycoalkaloids appear to be mainly unaffected by cooking, cutting, peeling, and other forms of preparation may vary the levels.

Commercial potato peel goods and chips can include large levels of glycoalkaloids, however the amount of glycoalkaloids in these products can vary greatly (Manach *et al*., 2018).

Low fats and calories

In practice, plant-based diets, whether they include starchy or non-starchy foods, tend to have a lower energy density compared to diets primarily based on animal-derived foods and high in sugar (Zhang *et al*., 2018). Potatoes are naturally low in fat and calories, which make them a healthy option for those looking to control their calorie intake and maintain a healthy weight. Without the addition of high-calorie toppings or additives, potatoes are considered a low-calorie food, containing approximately 440 calories per pound. They are high in carbohydrates and have a lower sugar content than other tuber vegetables such as carrots, sweet potatoes (ValcarceNavarre *et al*., 2019).

Proteases inhibitors

Protease inhibitors are well-known for their anticancer properties. Protease inhibitors are small molecular weight peptides (5 and 25 kDa) that form diverse protein group than patatin. Researchers discovered and extracted several protease inhibitors from potatoes (Raigond *et al*., 2023). Several studies demonstrated antitumor efficacy of potato protease inhibitors. StAPs have been proven in vitro and in vivo to exert anticancer action by inducing selective permeable membrane penetration and cytotoxicity in cancer cells. StAPs were also found to have a dose-dependent cytotoxic impact. Animal studies have indicated that StAPs reduce tumor growth in melanoma xenografts in arthymic nude mice (Kowalczewski *et al*., 2022).

Contribution to Health

A new evidence base is emerging to support vegetables and fruits protective effect in the prevention of cancer, diverticulosis, chronic pulmonary disease, and maybe hypertension (Van Duyn and Pivonka, 2000). The potato has been a staple of human diets for thousands of years, first in the Andes and then throughout the world. Cooking, potato consumption, and nutritional bioavailability all influence its contribution. The major phytonutrients present in potatoes, including minerals, proteins, and fibers, are often effectively preserved after cooking. Vitamins C and B6 are dramatically reduced after cooking, although anthocyanins and carotenoids improve quickly due to better release of these antioxidants from the food matrix (Tian *et al*., 2016). In summary, potatoes can be a nutritious and valuable part of a healthy diet when consumed in moderation and prepared in a health-conscious manner. Incorporating a variety of vegetables and balanced food choices into your diet is key to maximizing their contributions to human health (Table 3).

Table 3. Biological properties and biological/physiological effects of potato compounds

Biological properties	Used model	Dose	Compounds	Mechanisms & biological effects	References
Antioxidant activity	Male adult man	150 g cooked daily for 6 weeks	Phenolic acid anthocyanins	PP potatoes showed significant result as compared to YP and WP. Protect DNA and other biomolecules from oxidative damage by increasing the expression of cellular antioxidant enzymes. Also prevent lipids peroxidation.	Kaspar *et al*., 2011
	Rats (male Wistar)	Oral administration of 100 mg/kg	Peptides (Phe-Gly-Glu-Arg) (Phe-Asp-Arg-Arg) (Phe-Gly-Glu-Arg-Arg)		Kudo *et al*., 2009

Anticancer	Colon and liver cells HepG_2	100 mg/mL.	Chlorogenic acid, pelargonidin chloride, and malvidin chloride phenolic, protease inhibitors proteins and peptides anthocyanins, fibre, lactins, glycoalkaloids	Pigmented potatoes extract showed more significant result than white. Stop tumor cell proliferation and H2O2 production; inhibit UV-induced AP-1 activation, Limit cancer cell motility; induce apoptosis; alter tumor cell morphology; absorb mutagens, restrict protein, DNA, and RNA synthesis in cancer cells. Reduce metastasis. Reduces the activities of matrix metalloproteinase-2 (MMP-2) and MMP-9; cytotoxic to cancer cells, promote mitochondrial release and nuclear absorption of proapoptotic Endo G and AIF proteins, increase the expression of cellular antioxidant enzymes; inhibit cancer-related inflammatory mediators; and suppress ROS-mediated NF-kB, AP-1, and MAPK activation.	Camire *et al.*, 2009; Robert *et al.*, 2006; Pouvreau *et al.*, 2001; Langers *et al.*, 2009; Kenny *et al.*, 2013; Reddivari *et al.*, 2010; Freidman *et al.*, 2005; Hayashi *et al.*, 2006; Madiwale *et al.*, 2011; Yang and Yoon, 2012; Wang *et al.*, 2011
Antiobesity	obese-ob/ob mice,	150 and 300 mg/kg for 28 days	Phenolics, protease inhibitors, proteins & peptides.	Standardized potato extract comprising 5% PPI II, which produces a satiety response. Down-regulation of p38 mitogen-activated protein kinase (MAPK) and uncoupled protein 3 (UCP-3) expression inhibits lipid metabolism, Increase CCK release and also improve CCK response primarily by inhibiting trypsin-like proteolytic activity. Boost CCK1R expression in enteroendocrine cells; block luminal proteases	Ku *et al.*, 2016; Komarnytsky *et al.*, 2011; Chen *et al.*, 2012; Foltz *et al.*, 2008.

Antidiabetics	STZ-induced diabetic rats Male Wister rats	daily dose of 165 mg/kg b.w. for 14 days	Phenolics fibers, acylated anthocyanin petunidin-3-O-p-coumaryl-rutinoside-5-O-glucoside	Oral administration of extracts had lower fasting blood glucose and glycated hemoglobin levels in Diabetic rats. Reduce intestinal glucose absorption; lower oxidative stress and total food consumption, boost insulin sensitivity, inhibit hepatic glucose-6-phosphatase, regulates antioxidant enzyme activity, minimize glycemic response to meals, also liver and kidney hypertrophy.	Bassoli *et al.*, 2008; Singh *et al.*, 2005; Strugała *et al.*, 2019
Anti-inflammatory	Jurkat and Raw 264.7 macrophages	150 g of potatoes flashed for 6 weeks	Glycoalkaloids α-solanine, solanidine, α-Chaconine phenolic acids, anthocyanins, & carotenoids	Lower CRP, 8-hydroxydeoxyguanosine, and IL-6 levels in the blood. solanidine, α-Chaconine, Reduce IL-2 and IL-8 Con A-induced in Jurkat cells production; α-solanine, solanidine reduced induced NO production.	Kasper *et al.*, 2011; Kenny *et al.*, 2013
Antihypertensive	lead acetate (LAT)-induced hypertensive rats for 8 weeks	Ethanol extract of potatoes 200 mg/kg	Phenolic compounds, proteins & peptides	Minimize systolic and diastolic blood pressure by inhibiting angiotensin-converting enzyme (ACE), promote the production of cecal short-chain fatty acids. Also, ACE activity in blood was also suppressed by EGV treatment. EGV has an anti-hypersive activity via inhibition of ACE and can be used for the treatment hypertension.	Kim *et al.*, 2009; Mcgill *et al.*, 2013.

Anticancer properties

There is some evidence that eating green vegetables and fruits reduces the threat of cancer. (Boeing *et al.*, 2012). Some investigations found that polyphenol extracts from potato tubers have demonstrated the ability to inhibit the proliferation in prostate (Wang *et al.*, 2011) stomach (Bontempo *et al.*, 2013) liver and colon (Kubow *et al.,* 2017) cancer cells. Furthermore, potato extracts high in anthocyanins (Bontempo *et al.*, 2013) and glycoalkaloids (Nogawa *et al.*, 2019) demonstrated dose-dependent anticancer action in breast, cervical, and leukemia cancer cells. Several studies have found that using potato extracts reduces cancer cell proliferation. Antioxidants found in potatoes, including phenolic acids, fibers, anthocyanins, glycoalkaloids, and proteinase inhibitors, have been associated with the inhibition of both in vitro and in vivo cancer cell proliferation. The primary steroidal glycoalkaloids found in potatoes, are α -solanine and α -chaconine, have been extensively researched for their anticancer effects (Freidman, 2015). Potato peel has the highest concentration of α -solanine of any source. Study revealed that α -solanine may be an active and inexpensive source of cancer therapy. In addition, α -solanine is antipyretic, anti-allergic, anti-diabetic, anti-inflammatory, and antibiotic (Hassan *et al*., 2014). A study reported that α-solanine suppressed cancer cell proliferation via caspase 3-dependent mitochondrial apoptosis, and that it also reduced the production of proteins associated with tumor metastasis, MMP-2 and MMP-9 (Sun *et al*., 2014). Potato extract containing anthocyanins has been found to be more cytotoxic against prostate cancer cells (Reddivari *et al.*, 2019). Acrylamide may be present in fried potato products. Korean potato chips, for example, were found to have up to 4.0 g/kg acrylamide (Lee and Shim, 2007). Stomach cancer is inhibited by red and purple-fleshed potatoes (Rasheed *et al*., 2020). Numerous studies show that anthocyanin acts as an antioxidant against a variety of ailments, including dementia and colorectal cancer in mice (Lippert *et al*., 2017). Andean potato polyphenol extracts were tested for cytotoxicity against human neuroblastoma and hepatocarcinoma cell lines (Table 2). All cell types experienced a dose-dependent decrease in feasibility because of the treatments (Silveyra *et al*., 2019). During *in vitro* simulated gastrointestinal digestion, purple potatoes shown excellent antioxidant, antibacterial activities and additionally antiproliferative, against colon cancer cells (Caco2, SW 8) and breast cancer cells (MCF7, and MDAMB231) (Ombra *et al*., 2015). Extracts from purple potato have been shown to decrease colon carcinogenesis through killing cancer stem cells. Chlorogenic acid, and anthocyanins, have an anticancer impact. It has been shown to suppress the proliferation of prostate and colon cancer cells as well as protect against colon, liver (Charepalli *et al*., 2015).

Antioxidant effects

Due to their strong antioxidant capacity, anthocyanins and HCADs defend against several disorders brought on by reactive oxygen species (ROS). Phenols, particularly certain flavonoids have a strong capability to bind to free radicals and function as antioxidants, which has a positive impact on the prevention of cardiovascular, cancer, and neurological disorders (Ercoli *et al.,* 2021). When eaten with the skin on, the potato tuber has a lot of nutritional fiber. It also has a lot of antioxidant components (Samaniego *et al*., 2020). Phenolic chemicals, vitamin C, flavonoids, and carotenoids are the primary antioxidants. Phenolic acids, flavonols, and anthocyanin components are the four different forms of polyphenols that are present in potatoes (Zhao et al., 2020). Chlorogenic acid, which accounts for around 90% of the total polyphenol content (TPC) in potatoes, is the most prevalent polyphenol there. Compounds with antioxidant properties are abundant in potatoes. Due to their frequent use in the diet, studies have shown that potatoes are ranked in the third position among foods in terms of daily intake of antioxidant components, after oranges and apples. Many scientists have noted the beneficial impact of antioxidant components on human health. These studies demonstrate how ingesting foods with strong antioxidant qualities can improve the quality of diets. Moreover, scientists are always looking for novel natural substances having antioxidant properties, such as components of proteins, peptides, hydrolysates, polyphenols, and flavonoids (Burgos *et al*., 2019). Numerous epidemiological studies link dietary intake of polyphenols to the prevention of cardiovascular illnesses. The inhibition of oxidative stress, cell damage, protein damage, DNA damage and lipid peroxidation mechanism are said to be accomplished by polyphenols. Additionally, intake is linked to a reduction in the threat of neurodegenerative diseases including Parkinson's and Alzheimer's (Xing *et al*., 2019).

Anti-inflammatory effects

Potatoes contain a variety of anti-inflammatory compounds, including anthocyanins, which help to reduce inflammatory bowel syndrome and additional chronic disorders connected to gut health (Bibi *et al.*, 2019). External application of raw potato juice might relieve swelling of joints and muscles. Potato starch has anti-inflammatory effects and can help cure gastrointestinal inflammation (Umadevi *et al.*, 2013). Extract from peel was found to lessen the severity of dermatitis in Atopic dermatitis rats. A chloroform extract obtained from potato peels has been shown to reduce colitis severity and release proinflammatory mediators in rats induced with dextran sulfate sodium colitis (Kowalczewski *et al.*, 2022). Kujawska *et al.* (2018) investigated the role of spray-dried potato juice in the treatment of mucosal damage induced by mucosal inflammation. Research has shown that spray-dried potato juice can reduce the mRNA expression and production of proinflammatory cytokines like IL-6 and TNF-α in cultures involving Caco-2 and RAW264.7 cells that have been exposed to lipopolysaccharide. This indicates the potential anti-inflammatory properties of spray-dried potato juice in mitigating the proinflammatory response. It was also found to protect against lipopolysaccharide-induced intestinal barrier integrity disturbance. Spray dried potato juice at 200 -500 mg/kg doses was shown to lower TNF- expression in stomach mucosa and minimize the prevalence of ulcers in rats (Kujawska *et al.*, 2018). In comparison to white potatoes, for six weeks, eat 150 g purple potatoes on a regular basis, lowered the level of C-reactive protein and severe inflammation in healthy men. It is concluded that pigmented potatoes have higher anti-inflammatory effect. (Kaspr *et al.*, 2011). The concentration of anthocyanin in pigmented potatoes is said to have an anti-inflammatory effect (Zhang *et al.*, 2017). It was found that, in both animal models (Kujawska *et al.*, 2018) and human clinical trials (Jiao *et al.*, 2015), indigestible carbohydrates, specifically resistant starch and fiber, have demonstrated an impact on inflammatory markers. Anthocyanin enriched potatoes minimize colonic epithelial damage in colitis and improve gut absorptivity in rats. This research underscored the importance of the gut flora in the protective effects of anthocyanin-rich potatoes on the gut barrier. Because the medications used for the treatment of ulcerative colitis, (serious inflammatory bowel disease) have some negative side effects (Li and Reddivari, 2021). Hence, phenolics, glycoalkaloids, fiber, and resistance starch have direct impact of anti-inflammation in humans (Kenny *et al.*, 2013).

Antihypertensive and cardioprotective effect

Cardiovascular diseases (CVD) are among the most serious worldwide health concerns (World Health Organization, 2011). As a result, there is a lot of interest in nutraceuticals as agents for controlling hypertension and preventing cardiovascular disease. It is advisable to prepare and serve potatoes with minimal added fats, and it's also beneficial to consume the potato peels because they are a good source of dietary fiber. This dietary approach can help maintain heart health and overall well-being. Potato protein, and starches, (resistance and phosphorylated) have been shown to have cholesterol-lowering effects. Phytochemicals, particularly antioxidants, have been linked to a reduction in inflammation, which has been linked to cancer, cardiovascular disease, and diabetes. Potatoes, as a primary dietary source of mineral like potassium, vitamin C, and fiber, which contribute considerably to nutrients that play roles in improving cardiovascular fitness (McGill *et al.*, 2013). Potatoes contain low levels of sodium and have high levels of potassium content, and thus have the ability to treat hypertension-related conditions (Raigond *et al.*, 2023). In crossover research, 18 hypertensive individuals with an average BMI of 29 were given either 6-8 tiny microwaved purple potatoes twice a daily or no potatoes for four weeks, followed by four weeks on the reverse regimen. The potato had no effect on plasma glucose, lipids, or HbA1c and no noticeable rise in body weight. However, there was a significant reduction in diastolic blood pressure, with a decrease of 4.3% or 4 mm, and systolic blood pressure also decreased by 3.5% or 5 mm. Despite the fact that 14 of the 18 individuals were receiving antihypertensive medications, blood pressure dropped. That was the first study to look at how potatoes affect blood pressure and concluded that pigmented potatoes are an effective hypertensive gent that reduced the threat of cardiovascular diseases (Vinson *et al.*, 2012). kukoamines is a compound that is used to regulate blood pressure. N1, N12-bis (dihydrocaffeoyl) spermine (kukoamine A) and N1, N8-bis (dihydrocaffeoyl) spermidine have been identified in potato tubers. These compounds are part of the diverse array of phytochemicals found in potatoes. In comparison to other chemicals, the concentration of kukoamines in potatoes is quite high (Parr *et al.*, 2005). In vitro, peptides extracted from tubers inhibited angiotensin-converting enzyme (ACE) Isolates from immature (fresh) potatoes inhibited the least, while isolates from mature tubers, sprouting potatoes, commercial by-products inhibited the most (Pihlanto *et al.*, 2008). There is little known about the role of potatoes in the prevention of cardiovascular disease. There is some evidence suggesting that potato protein, resistant starch, and phosphorylated starch may contribute to the reduction of cholesterol levels. These components of potatoes could potentially have beneficial effects on cholesterol management and cardiovascular health. Phytochemicals, particularly antioxidants, have been linked to a reduction in inflammation, a risk factor for cardiovascular disease (Camire *et al.*, 2009). Potato tubers are naturally abundant in potassium, containing up to 400 mg/100 g fresh tubers or 1.7% DM (Schilling *et al.*, 2018). Because of its vasodilation action, potassium can help reduce blood pressure (Usmani and Mishra 2016).

Anti-diabetes and anti-obesity

The prevalence of diabetes is increasing globally, and further research is essential to establish and confirm the potential links between potato polyphenolic compounds and dietary fiber and their roles in diabetes prevention or treatment (Figure 2). Metabolomics has been used to study the impact of potato ingestion on blood sugar levels. As we know that, potatoes are a main source of carbohydrates. Different potato varieties and cooking methods can result in variations in the glycemic response. Metabolomics studies can help identify specific metabolites associated with blood sugar regulation after potato consumption, contributing to our understanding of their impact on conditions like diabetes. Potatoes contain resistance, so consumption of RS has been found to increase whole-body insulin sensitivity (Maki and Phillips, 2015). A main hazard for the development of T2D is decreased insulin sensitivity (i.e., insulin resistance), Several treatments that promote insulin sensitivity have been demonstrated to lower the incidence of newly-onset T2D (Kitabchi *et al.*, 2005). It has been revealed that the gut microbiota's fermentation of resistant starch (RS) is the mechanism through which insulin resistance may be influenced consequences. Because RS in the small intestine is not completely digested, it functions physiologically like a mixture of starch and dietary fiber (Sanders *et al.*, 2021). Short-chain fatty acids (SCFAs) such as acetate, propionate, and butyrate can be generated through the fermentation of resistant starch (RS) in the colon. These acids are taken into the bloodstream and have a variety of metabolic This fermentation process is carried out by gut bacteria and can have various health benefits, including contributing to the energy supply of colon cells and potentially influencing overall health and metabolic functions. (Keenan *et al.*, 2015). The first consequence is the inhibition of hormone sensitive lipase, which lowers the release of free fatty acids (FFA) from adipocytes (Kimura *et al.*, 2014). With an injected lipid emulsion, for example, raising plasma FFA levels for some hours causes insulin resistance, while lowering them for some hours with the niacin analogue acipimox increases insulin sensitivity (Oh *et al.*, 2018).

When administered as 10% of the meal, potato peel extracts, which are rich in polyphenolic compounds, have been observed to reduce oxidative stress, hyperglycemia (high blood sugar levels), and overall food consumption in diabetic mice. These findings suggest a potential role for potato peel extracts in managing oxidative stress and blood sugar levels in a diabetic context. (Singh *et al.*, 2005). The researchers found that long-term research is required to demonstrate the correlation between potato ingestion and diseases such as cancer, overweight, diabetes, and cardiovascular disease (Figure 2). Because current findings on potato consumption and disease management are conflicting. Some studies found potatoes to be effective in controlling obesity and diabetes, while others showed no benefit and others revealed a harmful effect of potato consumption on diabetes and obesity (Visvanathan *et al.*, 2016). 5-caffeoylquinic acid co- and pre-incubated with porcine pancreatic amylase inhibited amylase in five potato types (variable phenolic content). The dose of

5-caffeoylquinic acid was found to affect enzyme inhibition. Researchers concluded that many characteristics of potato tubers, such as dry weight, starch, phenolics, influence digestibility. In vivo research revealed that chlorogenic acid lowers blood glucose levels by inhibiting starch breakdown (Karim *et al*., 2017). Polyphenols found in potato juice have been shown to help people with weight loss and regulate their blood sugar levels. In rats fed a high-fat diet, a polyphenol-rich extract derived from potatoes-controlled insulin, leptin, and stomach peptide levels. Pure chlorogenic acid treatment improved insulin secretion regulation insulin sensitivity, and glucose tolerance, in animals (Kubow *et al*., 2014). Pigmented potato extracts were assessed for their capacity to inhibit α-glucosidase, aldose reductase activity, and α-amylase. These potatoes were characterized by high polyphenol content, particularly chlorogenic acid. The predominant anthocyanins in these potatoes included derivatives of malvidin, peonidin, pelargonidin, and petunidin. These compounds are of interest due to their potential role in modulating enzymes related to blood sugar regulation and their antioxidant properties. Purple fleshed extracts inhibited -amylase and –glucosidase, (IC50: 25 g/ml, and 42 g/ml respectively, and aldose reductase enzymes more effectively. These findings suggest that purple potatoes have the ability to manage diabetes by inhibiting carbohydrate degrading enzymes (Kalita *et al*., 2018). Diabetes is becoming more common all over the world. Further research is needed to establish the relationship between potato dietary fiber and polyphenolic content in the management of diabetes. Conducting additional studies will provide more concrete evidence and insights into how these components may influence diabetes and contribute to effective dietary strategies for diabetes management.

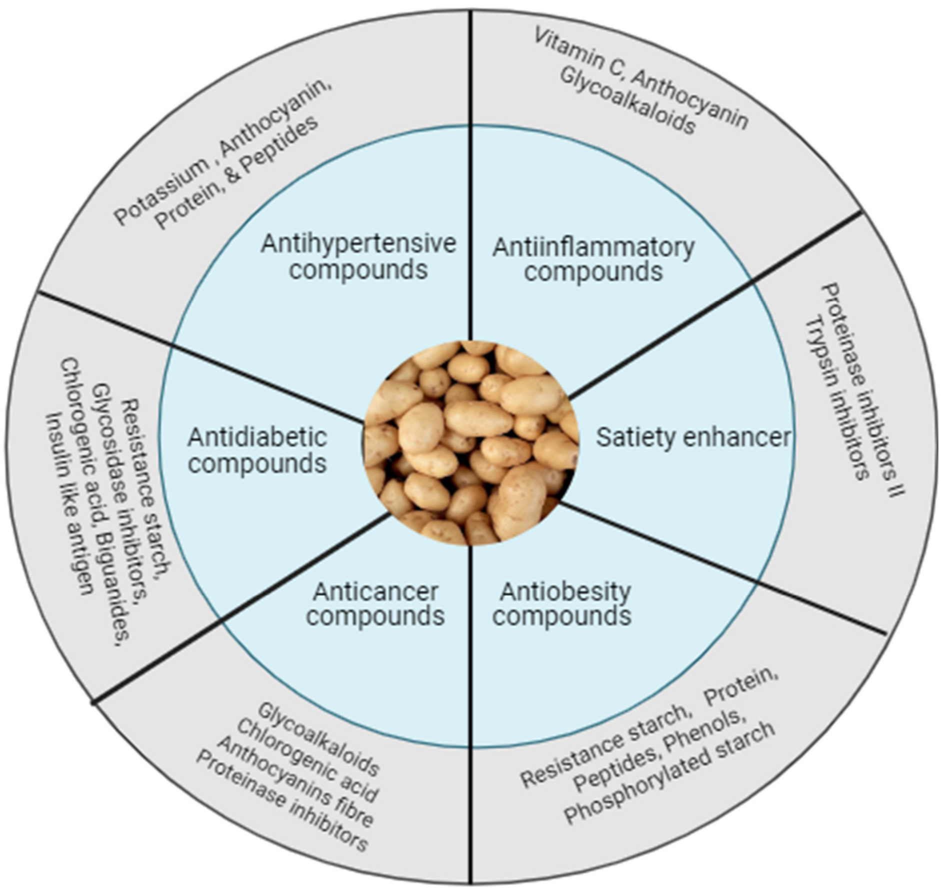


Figure 2. Health promoting compounds found in potatoes and their potential roles in disease prevention

Satiety enhancer

Foods with a high glycemic index (GI) have been claimed to decrease satiety and so promote obesity and overweight. Potatoes have a high GI in general, but they also supply numerous essential nutrients and are a vital dietary source worldwide (Leeman *et al.*, 2018). Potatoes have a high satiety index, which means they can help keep you feeling full and satisfied, potentially reducing overall calorie consumption. A comparative study found that participants reported feeling less hungry (with a mean (SD) measurement of 263 (230) mm min) after consuming a meal with potatoes compared to meals with rice (374 (237) mm min) or pasta (444 (254) mm min). Additionally, after the potato meal, participants reported feeling fuller, content, and having a reduced desire to eat, as compared to their responses after consuming pasta and rice ($p < 0.01$ for all). These findings suggest that potatoes may have a greater satiating effect compared to rice and pasta. This suggests that potatoes may offer a greater sense of fullness and satisfaction despite their lower calorie density. (Zhang *et al.*, 2018). A smaller portion decreases both the glycemic load (GI x grams' accessible carbohydrate) and the calorie content of the meal. As previously mentioned, potatoes may be an appropriate food option for reducing energy intake while maintaining satiety and decreasing postprandial glycemia since less carbohydrate is taken (Anderson *et al.*, 2013).

Metabolomic Biomarkers

Metabolomic studies may identify specific metabolites associated with potato consumption that could serve as biomarkers for assessing dietary intake and its effects on health outcomes. These biomarkers can be valuable in nutritional research and personalized nutrition. It's worth noting that the metabolomic potential of potatoes in human health is an evolving field of research, and the results can vary depending on factors like potato variety, preparation methods, and individual metabolism (Figure 3). Additionally, the interaction between potato consumption and overall dietary patterns plays a crucial role in determining its health effects. Therefore, more research is needed to fully understand the metabolomic intricacies of potato consumption and its impact on human health.

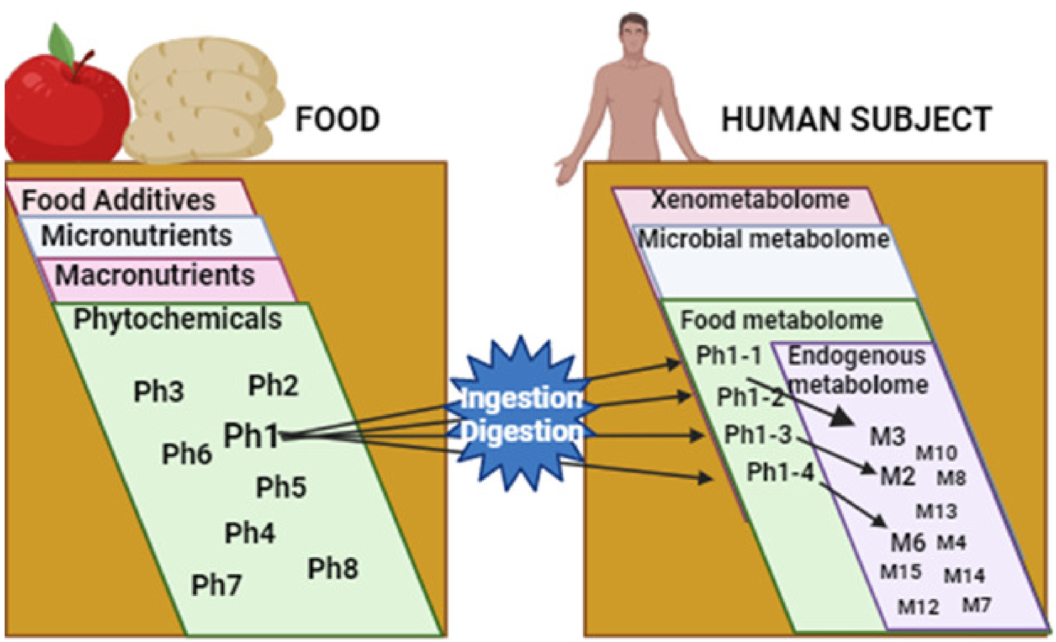


Figure 3. Dietary phytochemicals and their metabolite, impact on metabolism and health

Versatility

Potatoes can be prepared in a wide variety of ways, from baking and boiling to roasting and mashing. This versatility makes it easy to incorporate them into a balanced diet. Potatoes are versatile since they can be cooked, fried, steamed, roasted baked, and even pressed into French fries, chips, flakes, cubes, dumpling, flour, canned potatoes, and so on (Kulshrestha *et al*., 2017). Tuber quality attributes suitable to certain cooking or processing activities (boiling, frying, dehydration and baking etc.) can be used to classify varieties. These can be further subdivided. In case, cultivars suitable for frying are classified as chipped (round) or French fry (elongate)(Camire *et al*., 2009). However, it's essential to consider how potatoes are prepared and consumed. While plain boiled or baked potatoes are relatively healthy, deep-frying them into French fries or covering them in high-fat toppings can negate some of their health benefits and contribute to unhealthy eating habits. Potato flour is a versatile raw material that can be used in a variety of ways (Table 4). Two Mauritian varieties were floured and used to make gulab jamuns, mash, and paratha, three classic Mauritian dishes (Kulkarni *et al*., 1996).

Table 4. Products prepared from *Solanum tuberosum* L.

Product	Objective	Description	References
Potato flour	Bakery product (Biscuit)	Thermal treatment of SP flour was performed, and dough properties as well as final bread quality were investigated, considering mixes with wheat flour	Rowayshed *et al*., 2015
Potatoes peeled powder	Cake, bread	Peel powders high in fiber and protein were mixed into cakes, improving nutritional value (increased fiber content) and texture (decreased cake hardness)	Jeddou *et al*., 2017
Potatoes Snack	Snack, chips	Extruded products were fortified with protein, fiber, and beneficial substances. The acrylamide precursors in fried purple SP were investigated. The effect of frying oil unsaturation and its effect on acrylamide production was examined	Lee and Shim, 2007

Potatoes are incredibly versatile, and their products have a wide range of commercial applications. Here are some of the most common potato products and their commercial uses.

Fresh potatoes

Fresh potatoes are sold in various sizes and are used in a wide range of culinary applications, including baking, boiling, mashing, and frying. They are a staple in many dishes and are available in different varieties (Pedreschi *et al*., 2007).

French fries

French fries are one of the most popular potato products in the world. They are widely available in fast-food restaurants and as frozen products in grocery stores. The commercial production of frozen French fries involves cutting, blanching, frying, and freezing the potatoes (Arsalan *et al*., 2018).

Potato chips

Potato chips, or crisps, are a common snack food. They are thinly sliced potatoes that are deep-fried and seasoned. The commercial production of potato chips involves slicing, frying, and flavoring the chips (Pedreschi *et al*., 2007; Arsalan *et al*., 2018).

Dehydrated potato products

Dehydrated potato products include potato flakes, granules, and powder. These products are used in instant mashed potatoes, soups, and various processed foods. Dehydration extends shelf life and reduces transportation costs (Pedresch, 2009).

Potato starch

Potato starch is used in the food industry for its thickening and binding properties. It's also used in non-food applications, such as in the textile and paper industries (Dupuis and Liu 2019).

Potato flour

Potato flour is a gluten-free alternative to wheat flour and is used in gluten-free baking and cooking. It's also used in some processed foods (Kulkarni *et al*., 1996).

Potato dumplings

Potato dumplings are a traditional food product made from mashed potatoes and are popular in various cuisines. They are often commercially produced and sold in grocery stores (Jiang *et al*., 2018).

Potato-based snacks

Besides traditional chips, there are various potato-based snacks, such as tater tots, hash browns, and potato wedges, which are often available in commercial food service and retail settings (Sman and Broeze, 2013).

Potato bread

Potato bread is made by incorporating potato into the bread dough, which results in a softer, moister bread with a longer shelf life. It's available in many bakeries and supermarkets (Ijah *et al*., 2014).

Potato vodka

Potatoes can be used to make vodka. Some brands produce premium potato vodkas, often associated with a smoother and creamier taste compared to grain-based vodkas (Wisniewska *et al*., 2015; Menezes *et al*., 2017).

Animal feed

Potatoes that don't meet human consumption standards due to size, shape, or blemishes can be processed into animal feed, reducing food waste (Li *et al*., 2015).

Alcohol production

Potatoes can be used to produce alcoholic beverages like potato wine and some traditional liquors in certain regions (Arapoglou *et al*., 2010).

Biodegradable plastics

Plant proteins can also be used to make bioplastics, which are excellent for food packaging, film manufacturing, and medical uses. Potato starch and protein have been used in the production of biodegradable plastics, which are environmentally friendly and used in various applications (Priedniece *et al.,* 2017).

Medicinal products

Some pharmaceuticals use potato starch as a filler or binder in tablet production. The majority of phenolic compounds (up to 90%) are chlorogenic acid, which is not particularly valuable on its own but can be hydrolyzed into quinic and caffeic acids. it has significant antibacterial properties whereas quinic acid is a raw ingredient used in the synthesis of various drugs (Freidman, 2006; Priedniece *et al*., 2017). Starch has the potential to be employed in nanotechnologies and is a popular material when producing medical devices and nanotubes. Other uses for starch in the pharmaceutical industry include binders, fillers, various coatings, capsules, decomposable substrate, implant, former, and biotechnologies, which can use starch derivatives (non-ionic and ionic compounds) obtained through different chemical modifications (Lu *et al*., 2009).

Horticultural uses

Potatoes can be used for growing seed potatoes, which are then sold to farmers for planting in subsequent seasons.

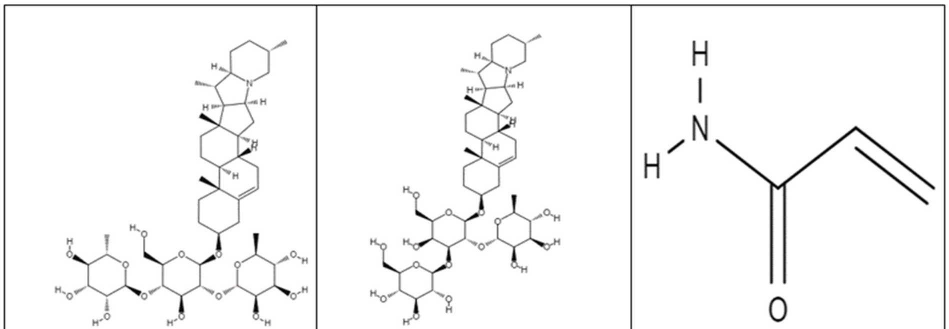
Advance Formulation in Field of Nanotechnology

Metallic nanoparticles are the most promising; they have good antibacterial capabilities due to their high surface-area-to-volume ratio. Which is of great interest to researchers due to rising microbial resistance to metal ions, antibiotics, and the emergence of resistant strains (Mba and Nweze, 2021).

Silver nanoparticles are commonly utilized in the medical profession as anti-microbial agents due to their powerful growth inhibitory effects against fungi, bacteria, and viruses, as well as their low toxicity to human cells. These nanoparticles have found use in food storage, textile coatings, and water remediation (Rai *et al*., 2009). Green synthesis methods were used to synthesize Ag nanoparticles from extracts of apples, oranges, potatoes, red pepper, white onion, garlic, and radish. The antibacterial characteristics of the nanoparticles were tested against *Staphylococcus aureus, Bacillus cereus, Escherichia coli, and Candida krusei*. Plant extracts offer silver nanoparticles particular features, although the highest antibacterial properties indicate nanoparticles formed in the presence of potato extract (Wasilewska *et al*., 2023). Selenium nanoparticles, which are also known to possess antioxidant, antimicrobial activity, were also synthesized from using potatoes extract. Selenium nanoparticles are commonly employed in medical applications such as drug delivery. The antioxidant activity of Hallow selenium nanoparticles (hSeNPs) was shown to be concentration-dependent. The hSeNPs were effective against both gram-positive *Bacillus subtilis* and gram-negative *Escherichia coli*. According to the findings of this study, potato extract lessens the toxicity of hSeNPs, and lower doses of hSeNPs could be used for a variety of biological applications in the near future. (Chandramohan *et al*., 2019). Starch nanoparticles were synthesized using potato peel extract. These assessed against antioxidant activity and showed promising results (Hasanin, 2021). Starch capped silver nanoparticles were synthesized by using aqueous extract of potatoes. Starch-capped AgNPs exhibit antibacterial activity against E. coli and S. aureus. The minimum inhibitory concentrations for E. coli and S. aureus were determined to be 6.4 g/ml and 8.2 g/ml, respectively. The specific metal binding capacity of cysteine is responsible for the reduction of adsorbed $Ag+$ onto the surface of silver nanoparticles in the protein cell wall (Khan and Al-Thabaiti 2019).

Toxicology Studies

Although natural substances derived from plants have successfully led to the development of key medications that are still used to treat a variety of diseases, many herbal products are inadequately studied or monitored, if at all, for their efficacy and safety. Plants as therapeutic medications are not as safe as promised, and some medicinal herbs may have negative side effects. As a result, it is critical that toxicological studies be conducted and that proper information on the hazards connected with the use of these products be supplied to customers (Oyedepo *et al*., 2021). Heat-inducing interactions between the amino group of the amino acid asparagine and the carbonyl groups of glucose and fructose in plant-derived foods such as potatoes, produce potentially lethal acrylamide (Friedman, 2015). According to the American Cancer Society, acrylamide is generated when starchy foods such as potatoes and potato products are cooked at temperatures above 121 degrees Celsius. Deep frying at 170 °C, on the other hand, is known to efficiently cut the level of hazardous chemicals, whilst microwaving is only marginally effective, and freeze-drying or dehydration has no effect. Acrylamide levels are higher in CHO-rich foods like potato chips and French fries. Potatoes also contain poisonous chemicals known to cause poisoning, such as α-solanine and α-chaconine (Figure 4). These toxins produce gastrointestinal upset, resulting in vomiting and diarrhea, but severe poisoning can result in paralysis, heart failure, and coma. Green spots in potatoes containing chlorophyll are safe, although they signal the presence of toxins (Gupta and Gupta, 2019).



α-chaconine	α-solanine	Acrylamide

Figure 4. Chemical structure of poisonous chemicals presents in potatoes, known to cause poisoning, such as α-chaconine, α-solanine and acrylamide

Conclusions

Potato is one of the world's record essential staple food crops, including a variety of biologically active compounds carbohydrates, protein, lipids, and vitamins as well as phytochemicals like phenolic acids, carotenoids, anthocyanins, and flavonoids. Peels of potato are widely available and contain a diverse range of chemicals that could be employed in both food and non-food applications. Potatoes have proven to be useful in the food industry, medicinal uses, and packaging. Anthocyanins, polyphenols are the key pigments responsible for the in colored fleshed potatoes, have been recognized for their contributions to health due to their significant antioxidative activity, and anti-stomach cancer action. These phytochemicals, together with other critical nutrients have been demonstrated in both in vitro and in vivo tests to be more powerful antioxidants. So far, research has shown that potato phytochemicals have powerful anti-cancer, antidiabetics, antihypertensive, and GI reducing properties. The scientific community must promote greater phytochemical and pharmacological consideration of potatoes and their potent therapeutic activity, which would be significant in lowering the risks of tumors, diabetes, and cardiovascular disease.

Looking ahead, more research is needed to fully understand the health benefits of potato phytochemicals, focusing on their absorption and effects in the body. Clinical studies should explore how these compounds work to fight diseases, while breeding programs can develop potato varieties with enhanced nutritional properties. There is also great potential to use potato waste in eco-friendly products, helping to reduce waste. With further exploration, potatoes can play a larger role in both improving human health and supporting sustainable industries.

Authors' Contributions

Conceptualization: YZ, XH, AQ, XY, YB; acquisition of data, analysis, interpretation of data, writing - original draft: SI, AQ, YB, XY; Writing - review and editing: LY, XP, XL, JY. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

Acknowledgements

This work was supported by the National Key Research and Development Program of China (2022YFD1100402).

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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