Solanum tuberosum L: Botanical, Phytochemical, Pharmacological and Nutritional Significance

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REVIEW ARTICLE

Solanum tuberosum L: Botanical, Phytochemical, Pharmacological and Nutritional Significance

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Abstract

Solanum tuberosum commonly known as potato belongs to solanaceae family. The whole part of potato plant including leaves; tuber, peel and juice are used in traditional medicine. A number of pharmacological activities of potato have been reported viz. Antioxidant, anticancer, antiallergy, antibacterial, anti-inflammatory, antiobesity, anti-ulcer activity. Potato contains Phenolic acids, anthocyanin, flavonoids, vitamin B6, vitamin B3, pantothenic acid, potassium, manganese, phosphorous; copper and fibres. The medicinal properties, traditional uses, nutritional value, phytochemical constituents, taxonomy, geographic origin and distribution have been mentioned in this present review to provide collective data for multipurpose benefits.

Keywords: Solanum tuberosum; potato; Phytochemical; Pharmacological; anti-inflammatory

Introduction

The utilization of potatoes throughout the world is moving from fresh to processed potato product such as fries, chips, canned and mashed potatoes and ready meals [1, 2]**.** *Solanum tuberosum* L. (Solanaceae) known as potato is presently the fourth most important staple food crop in the world after maize, wheat, and rice, with a production of 368 million tonnes [3]. It is highly nutritious with carbohydrates (22%), proteins (2%), fats (0.1%), water (74%) along with minerals and trace elements viz. potassium, sodium, iodine and magnesium, folic acid, pyridoxine, vitamin C, ascorbic acid and Iron [4]. Around the world, this famous vegetable is divided not only by variety and species, but also by colour. Most potatoes are available in different shades of yellow, along with surprisingly blue (purple) and red fleshed varieties used as a natural colorant for food, including healing of wounds caused by burns [5]. It is also known with different names in different languages(Table.1).

Table 1 Different Vernacular Names of *Solanum tuberosum* L.

Serial Number	Name	Language
1.	Aalu	Bengali
2.	Batata	Gujarati
3.	Alu	Hindi
4.	Urulaikkilangnku	Tamil
5.	Potato	English
5.	Alugedde	Kannada

Apart from being one of the main and most consumed types of food by the world population, the potato waste formed by peel and damaged potatoes with a rich source of valuable compounds is also applied in bio-fuel production or animal feed.It has in-

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credible and remarkable medicinal value used in any form viz, mashed, raw, boiled and peeled[6].

The plants possess phenolic compounds which act as a protection against various microorganisms such as bacteria, fungi, virus, and insects. Potatoes show strong antioxidant capacity among most frequently consumed vegetables. A Russet potato, one of the favourite varieties in North America, contains the second highest antioxidants only slightly after broccoli in its hydrophilic antioxidant capacity. Potato peel is rich in fibre, zinc, iron, calcium and potassium along with B & C vitamins. Potato (*Solanum tuberosum*) is a useful source of bioactive compounds. Apart from starch, crude fiber, vitamins, amino acids, and minerals, the tubers incorporate various phenolic compounds which constitute the bulk of natural antioxidants [11, 12]. These phenolics and amino acids present with anti-oxidant protection towards tissue damage, reactive oxygen species and diseases like atherosclerosis, diabetes mellitus, renal failure, and cancer [9]. It has been found that bioactive compounds are most concentrated within the leaves as an alternative than stems and roots [10].Potato peels contain phenolic acids. The largest part made up of chlorogenic acid (CGA). Other phenolics such as caffeic acid (CFA), gallic acid (GAC), and protocatechuic acid (PCA), are present in low amounts in potato peel [13].

In this present article, we are presenting the unconventional ways of using potatoes and their peel to obtain value added products and compounds that can be used for innovative products in the market, by performing novel technologies with higher efficiency then conventional ones.

Taxonomy and Geographic Origin

Taxonomy

Potato (*Solanum tuberosum* L.) belongs to the Solanaceae family, comprising of about 90 genera and 2,800 species. *S. tuberosum* is divided into two, only slightly distinctive, subspecies: andigena, a diploid which is adapted to short day conditions and is typically grown in Andes; and tuberosum, a tetraploid potato now cultivated around the world, is believed to be descended from a small introduction of and igena potatoes to Europe that later adapted to longer day lengths[8]. The modern comprehensive taxonomic treatment of part potato acknowledges eight cultivated species and 228 wild species, divided into 21 taxonomic series, including 19 series for tuber-bearing species and two series of non-tuberous species [15].

The eight cultivated species in potato are provided in Table 3. Among these eight cultivated species of part Potato only *S. tuberosum* ssp. tuberosum is grown widespread.

Table 2 Botanical Classification of potato (*Solanum tuberosum* L).

Kingdom	Plantae
Subkingdom	Viridaeplantae
Division	Tracheophyta
Subdivision	Spermatophytina
Class	Magnoliopsida
Order	Solanales
Family	Solanaceae
Genus	Solanum
Species	*Solanum tuberosum* L.

Table 3 Cultivated Potato species with their Chromosome Number and Ploidy level

Solanum species	Chromosome number	Ploidy level
S. phureja S. ajanhuiri S. stenotomum S. goniocalyx	2n=2X=24	Diploid
S. juzepczukii S. chaucha	2n=3X=36	Triploid
S.tuberosum ssp. andigena S.tuberosum ssp.tuberosum	2n=4X=48	Tetraploid
S.curtilobum	2n=5X=60	Pentaploid

Geographic origin and Distribution

Potato is not a native crop of India. The cultivated potato originated around 8,000 years ago near Lake Titicaca, which sits at 3,800m above sea level in the Andes mountain range of South America, on the border between Bolivia and Peru [16]. The potato (*S.tuberosum*) was originated into Spain from South America within the latter half of the sixteen century. From Spain, the potato was descended to adjacent countries and within 100 years was being grown fairly extensively in many regions of Europe. Distribution beyond Europe quickly occurred with the introduction into India in the seventeenth century and China and Japan in the eighteenth century. By 20^{th} century potato finally emerged as an international commodity.

Distribution in India

In India potato saw its origin by either Portuguese or British colonizers in the early 17^{th} century. The earliest literature reference of potatoes in India is from the account of the voyage of Edward Terry, who was chaplain to a British Ambassador Sir Thomas roe, to the court of Mughal Emperor Jahangir from 1615-1619. The early potato introductions in India belong to *S. tuberosum* ssp. Andigena. The main improvement in potato production in India came after the establishment of CPRI in the year 1949 and the crop is currently being grown in 1.99 million hectares spread over 26 states.

Proteins	Starch	Glycoalkaloids	Phenolic Compounds		Phytonutrients	
Bioplastics	Bioethanol, bioplastics, textile, cosmetic, pharmaceutical & paper industry	Food supplements	Medicine Capsules for medicine	Packaging Materials	Food coloring	Medicine for wound healing

Figure 1 Potatoes and their peel uses in Industries

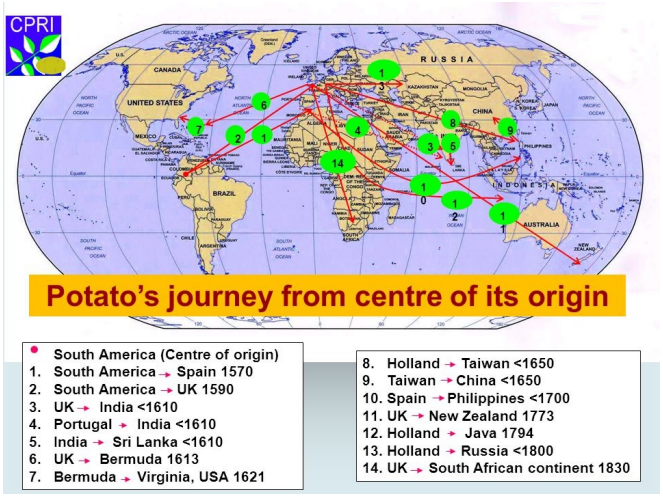


Figure 2 Potato's journey from centre of its origin. Source: Biology of Solanum Tuberosumby MoEF&CC

Botanical Description

Habit: The Potato is anon-woody (herbaceous) plant and grows habit varies between the species. The plant has a rosette or semi-rosette characteristics. Potato herbs are Annual, biennial or perennial.

Tuber: - Potato is an annual non-woody (herbaceous) plant, mainly reproduced vegetatively via tubers and typically by botanical seeds, i.e., True Potato seeds. The Potato tuber is an enlarged part of an underground stem from which new shoots are produced. The Tuber is morphologically a fleshy stem, carrying buds and eyes in the axil of small scale like leaves. Eyes are concerted near the apical end of the tuber, with small number near the stolon or basal end. Eye number and distribution are characteristics of the variety.

Stem: - In the early stages the stem is erect. Later it becomes proliferate and prostate.

Leaves: - The leaves are alternate and compound, asymmetrically odd pinnate, with 6-8pairs of leaflets and smaller, unequal interstitial leaflets; petiole consist of 2.5-5cm long, ovoid shape of leaflet blade from 1-6cm to 2-10cm, dark green color, terminating in a residual pinnate, mostly sparingly pilose. Buds formed in the axil of the leaves produce rhizome which extend rapidly and develop tubers at their extremities.

Roots: Fibrous or tuberous tap root.

Seed: -Endospermic seed.

Flower:- In flowers two types of pollination takes place one is self-pollination by themselves other from cross pollination by insect, bees, and birds. (Figure 3-5a-c)

Floral biology of Potato (Solanum tuberosum L) Flower

The terminal bud forms lateral flowers, inflorescence consisting of 1-30 (usually 7-15) flowers, depending on the maintenance and cultivation. The five petals form a star shape open flower. A flower of a pistil protrudes to form a cluster of five large bright yellow anthers.

The corolla color varies from white to complex range of red, blue, and purple. Flower opening begins nearest the base of the inflorescence and proceeding upward at the rate of about 2-3 every day. Flowers are open for only 2-4 days and the receptivity of the stigma and period of pollen production is about 2 days. The peak time of pollination takes place in early morning.

Nutritional Value

Potatoes have been found to be a particularly nutritious vegetable. Starch is the predominant aspect of potatoes, but they also contain small amounts of protein and alkaline salts. They are complex carbohydrate in the form of sugars, practically free of fats and cholesterol. Large amount of vitamins present in potato are beta-carotene, vitamin C, A, B1, B2, B6, and Folic acid. Many of the Nutrients in potatoes are found in their skin,

Figure 5a: The star shaped flower of Solanum tuberosum

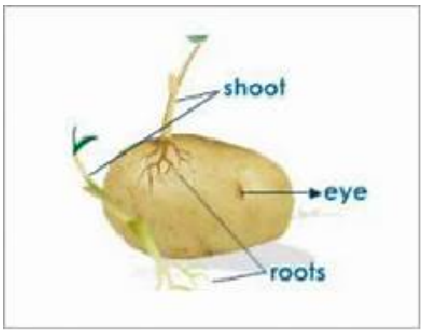


Figure 5b: The tuber of potato Solanum tuberosum

Figure 5c: The leaves of Solanum tuberosum

Figure 3 A botanical diagram describing the leaves, flower, seed, and various other arrangements of *Solanum tuberosum* L plant.

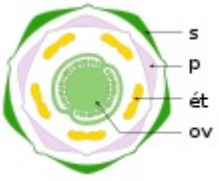


Figure 4 Floral diagram of Potato flower

Table 4 A Botanical description of the Potato Flower

Table 4: Details of the Solanum tuberosum L. inflorescence.

Inflorescence	Solitary orcymose
Flower	Actinomorphic, Bisexual,
Calyx	United, Sepals five, persistent valvate aestivation
Corolla	United, Petals five, velvet aestivation
Androecium	Stamens five, epipetalous
Gynoecium	Syncarpoes, bicarpellary, ovary superior bilocular, placenta with many vacuoles.
Fruits	Capsule or Berry
Seeds	many, endospermous
Floral formula of potato flower	$Br \oplus \varnothing K_{(5)} \overset{\frown}{C}_{(5)} A_5 G_{(2)}$

and so more benefits were attributed to consuming them entire as opposed to peeled [17].

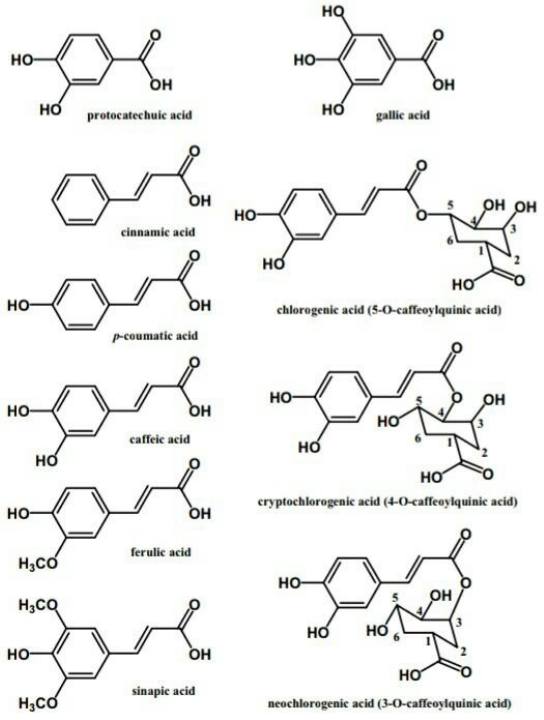
Phytochemical Analysis

Phytochemicals are the chemical substances present naturally in plants known for their numerous medicinal uses. Unlike pharmaceutical chemical compounds these phytochemicals do not have any side effects playing a central role against number of illnesses such as arthritis, asthma, cancer etc.[19].They are richly found in Fruits and vegetables. Polyphenols and carotenoids are two main phytochemical antioxidant groups found in vegetables. Polyphenols is a collective term for a few Sub-groups of Phenolic compounds including flavonoids, Phenolic acids, and anthocyanins [20].They are plant secondary metabolites no longer important to human health, but have been found to contribute significantly to therisk reduction of human chronic diseases corresponding to cancer and heart disease.

Phenolic acids

Phenolic compounds are particularly heterogeneous type of secondary plant metabolites which can broadly be categorized in phenolic acids (C6-C1 and C6-C3 structures). The major phenolic acids in potato are cinnamic acid and its derivatives, although benzoic acids such as gallic and protocatechuic acid are also found to be present. The phenolic acid profile in potato is reported to contain chlorogenic acid (50.3%) caffeic acid (41.7%), gallic acid (7.8%), and protocatechuic acid (0.21%). Phenolic acid play a significant function in the first line defence against insects and pathogenic microbes [20]. Although other phenolic acids are found in potato, the majority are cinnamic acid derivatives. These benzoic acids or cinnamic acids are synthesized in potato through the shikimate pathway. Chlorogenic acid (5-O-caffeoylquinic acid) is an ester formed between the carboxyl group of caffeic acid and the 5-hydroxyl group of quinic acid. The hydroxyl group at 4- or 3- position of quinic acid also forms esters with caffeic acid, resulting in isomers cryptochlorogenic acid and neochlorogenic acid, respectively, i.e. 4-O-or 3-O-caffeoylquinic acid.

Polyphenols possess abundant micronutrients in our diet, they protect cells and body chemicals against damage caused by free radical, and they have more beneficial antioxidants in vitro thantocopherols and ascorbate. Antioxidant properties of polyphenols arise from their high reactivity as hydrogen or electron donors, and from the ability of the polyphenol derived radical to stabilize and delocalise the unpaired electron (chain-breaking function), and their ability to chelate transition metal ions (termination of the Fenton reaction) [23]. It constitutes 90% of the phenolic compounds in potato peels and exists in the form of three important isomers, chlorogenic acid (5-*O*-caffeoylquinic acid), neochlorogenic acid (3-*O*-caffeoylquinic acid), and cryptochlorogenic acid (4-*O*-caffeoylquinic acid) caffeic acid [24].

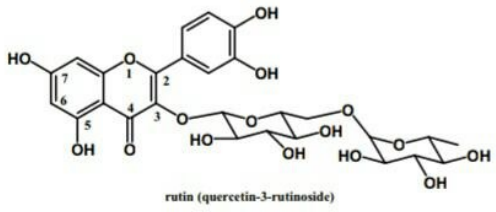


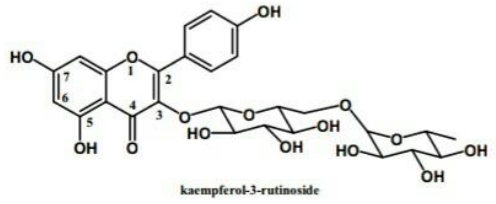
Structure of phenolic acids and derivatives from Potato

Flavonoids Flavonoids signify essentially the most common group of plant phenolic compounds and their presence influences the flavor and color of fruits and vegetables. The six important subclasses of flavonoids are the flavones, flavanones, flavan-3-ols, flavonols, anthocyanidins, and isoflavones. Occasionally they can be found as aglycones however most flavonoids are attached to sugars (glycosides) [25].

Apart from modifications to the C6-C3-C6 core, the marked structural variety of the flavonoids is a result of their conjugation to sugars at different sites of the molecule, frequently to one or more hydroxyl groups or, less usually, C-glycosidically to an aromatic carbon atom[26].

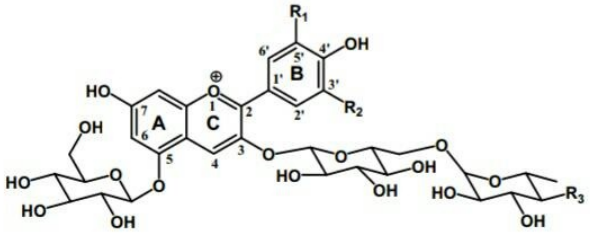
Catechins belong to flavan-3-ols which are frequently determined in tea or fruits such as apple and grape (mainly in the skins). Catechins are known as strong antioxidants which had been associated with several potential health benefits. Catechin is only a minor constituent in potato (10-13mg/100 g FW), as used to be observed in some cultivars [27]. Flavonols such as quercetin and kaempferol are close to ubiquitous during the plant kingdom, and are a particularly essential phytochemical group in our diets.





Structure of major flavan-3-ols (catechins): Catechin and Epicatechin. Major Flavonols: Quercetin and Kaempferol glycosides

Anthocyanins Anthocyanins are a sub-division of pigmented flavonoids. Cultivated varieties of potato incorporate various amounts of anthocyanins and carotenoids within the tuber skin and flesh. Potatoes have acylated glycosides of a few aglycons: pelargonidin, petunidin, malvidin, and peonidin [28]. Anthocyanin compound in fruits most likely exist in glycosidic forms, and the colour of a specified anthocyanin compound depends upon the hydroxylation or methoxylation patterns on the B ring. The anthocyanin composition is complicated in pigmented potatoes, with acylation in the glycoside ring. Anthocyanin pigment is responsible for the purple and red colors of potato varieties. Anthocyanin-containing red-fleshed potato Inca Red (red potato) and purple-fleshed potato Inca Purple (purple potato) have beenbred from hybrid seedlings between cultivars of Solanum tuberosum ssp. tuberosum and S. tuberosum ssp. andigena. Recently, potato anthocyanins have been recognized for their contributions to health, as they have been shown to have strong antioxidative activity, anti-influenza virus activity and anti-stomach cancer activity Structure of Anthocyanin(Mori et al.,2010).



Structures of anthocyanins in red and purple-fleshed potatoes

Carotenoids:

Aglycone	R1	R2
Pelargonidin	H	H
Cyanidin	OH	H
Delphinidin	OH	OH
Peonidin	OCH_3	H
Petunidin	OCH_3	OH
Malvidin	OCH_3	OCH_3

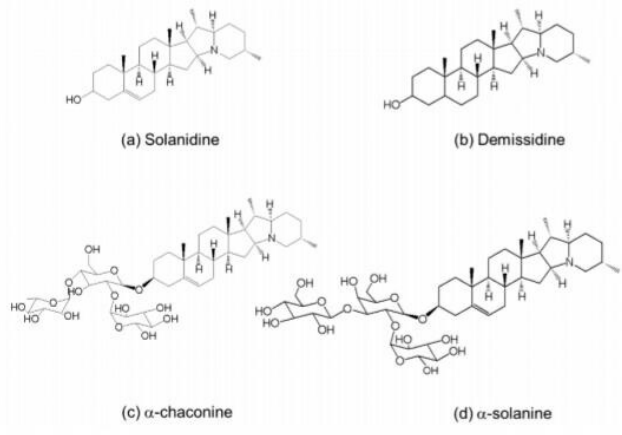
The carotenoid present in four white and yellow-fleshed potato cultivars (S. tuberosum) was identified by antheraxanthin, violaxanthin, Zeaxanthin and lutein, which are present in different proportions, whereas β-Cryptoxanthin, β-carotene and neoxanthin,are minor constituents [30].

Alkaloids:

Glycoalkaloids are plant secondary metabolites which are toxic to microorganisms, viruses, insects, animals and humans. The primary glycoalkaloids present in potatoes are α-solanine and α-chaconine, which share the equal aglycons, solanidine. Structurally, these compounds vary in the saccharide moiety in that α-solanine contains the trisaccharide solatriose, whereas in α-chaconine the aglycone is attached to chacotriose. Stepwise removal of a sugar moiety from the trisaccharides results in the formation of β and γ-glycoalkaloids and finally to solanidine, which show a lower toxicity compared to the parent compounds [26]. The glycoalkaloid content of potato tubers can vary extensively and is influenced by post-harvest factors such as exposure to light, irradiation, mechanical injury and conditions of storage.

Potato peels are rich source of steroidal alkaloids which are well known for their toxicity for human consumption in considerably high concentration (>1 mg/g dry weight sample). However, recent studies have demonstrated that these compounds also possess useful properties such as anticancer and anti-inflammatory effects depending on dose and conditions of use particularly; α-chaconine has demonstrated identical anticancer activity to that of the commercial anticancer drugs such as tamoxifen [31].

Structures of Glycoalkaloids: (a) Solanidine, (b) Demissidine, (c) α-chaconine, (d) α-solanine



Therapeutics

Potatoes are tremendous sources of both iron and folic acid, which are essential for formation of red blood cells finding their application in aiding treatment of different forms of anaemia. With their high mineral and organic salt content potatoes are recommended as one of the best anti-inflammatory foods for arthritis. At the domestic circuits raw potatoes with their anti-irritating, soothing and de-congesting properties are best applied for healing wounds caused by burns or rashes[38].Raw potato juice and slices with their anti-aging property remove dark circles and prevent wrinkles on face and make face glow. Potato cream or Mashed Potatoes are an excellent treatment for scurvy. Steamed or Boiled potatoes promote the formation and passage of soft, hydrated stools making them effectively used as a natural remedy to treat constipation and to prevent haemorrhoids. Detoxifying property of potatoes finds its application in treating toxic conditions such as rheumatism. Potatoes have low calorie content making them as an excellent alternative to cereals and grains for weight reduction regimen [39].Antioxidants play enormous roles in preventing oxidation of food and in retaining good human health. Potato contains the lowest quantity of total and free dry weight phenolics, making it the second best antioxidant quality based on the total phenolic contents. Oxidation of LDL cholesterol is linked to atherosclerosis, heart attacks, arterial blockage, and strokes. Because of the antioxidative nature of potato phytochemicals, consumption of good quality potato can make contributions to the prevention of LDL oxidation, therefore lower the risk of cardiovascular and heart diseases [40].

The potato tubers are used as anti-ulcer, anti-gout, anti-arthritic, anti-inflammatory, diuretic, and anti-scurvy and to increase milk in lactating mothers. [42].The inhibitory activity of polyphenols towards key enzymes such as α-amylase, α-glucosidase and phosphorylase which are primary in starch and sugar metabolism is considered to be important in reducing the GI, and more importantly in reducing risks of diabetes. Studies have found that potato anthocyanins can inhibit the growth of the cell line of human erythrocyte leukaemia and their potential anti-cancer role in stomach, pancreatic and breast cancers[43].

Conclusion

Potatoes (*Solanum tuberosum* L.), being one of the vital predominant staple food crops of the World, contains diverse biologically active phytochemicals, in addition to carbohydrates and protein and vitamins. They comprise a rich source of phenolic acids, flavonoids, phytates, folates, anthocyanins and carotenoids. Potato peels as a by product from potato processing are available in large amounts and it contains a wide variety of compounds that could be used in foods and in non-food applications. Potatoes have proved to be applicable for use in food production, pharmacy, medicine applications and packaging. It is well suited to deliver antioxidative phytochemicals and recent development in pigmented potatoes containing high concentrations of anthocyanins and carotenoids has generated even more interests in the potential health promoting role of potato [8]. Anthocyanins are the important pigments responsible for the red and purple fleshed potatoes, were recognized for their contributions to health, as they have been shown to have strong antioxidative activity, anti-influenza virus activity and anti-stomach cancer activity. Polyphenols possess excellent structural chemistry for free radical scavenging activity and these phytochemicals, together with different essential nutrients such as tocopherols, have been shown to be more potent antioxidants in vitro and in vivo studies One-third of all cancers are considered avoidable with the aid of altering dietary habits alone [21]. Literature so far has presented potent anti-cancer, anti-ulcer, anti-LDL peroxidation, and GI lowering activities of potato phytochemicals. The scientific community has to encourage further phytochemical and pharmacological dissection of potato and its potent healing activity which would prove significant in lowering the risks of cancer, cardiovascular diseases and diabetes.

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Table 5 The table describes the various secondary metabolites present in the potatoplant with the source of location and biological activities.

Class of compound	Name of the Compound	Source	Biological Activities	References
Phenolic acids				
Benzoic acids	Gallic acid, Vanillic acid, Protocatechuic acid, Salicylic acid	Tuber, peel	Antioxidant activity, Antibacterial activity,	[41]
Cinammic acid	5-O-Caffeoylquinic acid (chlorogenic acid), 4-O-Caffeoylquinic acid (crypto-chlorogenic acid),3-O-Caffeoylquinic acid(neo-chlorogenic acid) caffeic acid, P-Coumaric acid, Ferulic acid			
Flavonoids	Eriodyctiol, Kaempferol Glycosides, Quercetin Glycosides, Catechin, Epicatechin, naringenin	Tuber	Antibacterial activity Anti-ulcer activity	[41,42]
Anthocyanins	Petunidins, Malvidin, Pelargonidin glycosides, Peonidin glycosides.	Tuber	Antitumor activity, antibacterial activity, strong antioxidative activity, anti-influenza virus activity and anti-stomach cancer activity	[32,33,35, 41]
Protein	Patatin	Tuber	antioxidant or antiradical activity	
Amino acids	N^1,N^{12}Bis(dihydrocaffeoyl)Spermine, N^1,N8-Bis(dihydrocaffeoyl)Spermidine, N^1,N4,N^{12}-Tris(dihydrocaffeoyl)Spermine, N^1,N4,N8-Tris(dihydrocaffeoyl)Spermidine	Tuber,		
Carbohydrate	Tuberonic alpha Glucosidase	Leaves, Tuber	GI lowering Activities.	[28,35]
Alkaloids	α-solanine, α-chaconine Calystegin-B2(1,2,3,4-Tetrahydoxynortropane	Tubers, peels, sprout Leaves	Cytotoxic action on human cancer cells	[34,35,36]
Vitamin	α-Tocopherol(vitamin E), Folic acid(Vitamin B9)	Tubers	Antioxidant activity	
2-Carboxyarabinitol-1-phosphate	Potent inhibitor of Photosynthetic Enzyme Ribulose-1,5-bisphosphate carboxylase	Leaves		[37]
Carotenoids	β-Carotene, Cryptoxanthin, lutein, Zeaxanthin, Violaxanthin, Antheraxanthin, Neoxanthin	Tuber		
Phytic acid		Tuber	antioxidant, anti-cancer, hypocholesterolemic and hypolipidemic activity	

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