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Posted Date: 18 May 2023

doi: 10.20944/preprints202305.1317.v1

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Review

Functional Food Based on Potato

Yang Li [1], Lovedeep Kaur [2], Jaspreet Singh [2], Jian Xu [1,*] and Fankui Zeng [1,*]

[1] Research & Development Center for Eco-material and Eco-Chemistry, Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences, Lanzhou 730000, P. R. China
[2] Riddet Institute and School of Food and Advanced Technology, Massey University, Palmerston North, New Zealand
* Correspondence: xujian1980@licp.cas.cn (J.X.); zengfk@licp.cas.cn (F.Z.)

Abstract: Potato (Solanum tuberosum L) gradually becomes a stable food worldwide since it can be treated as practical nutritional supplement and antioxidant, as well as energy provider for human beings. Financially and nutritionally, cultivation and utility of potatoes is worthy enough attention of the world. To further explore functionality and maximize utilization of component parts, also to develop new products based on potato still be an ongoing issue. To maximize the benefits of potato and induce new high-value products while avoiding unfavorable properties of the crop has been a growing trend in food and medical areas. This review intends to summarize the factors that influence the changes in the key functional components of potatoes and discuss referred research focuses, then help further researchers to make efforts into. Afterwards, it summarizes the application of the latest commercial products and potential value of components existing in potato. Particularly, there are several main tasks for the next potato research: preparing starchy foods for special group of people and developing fiber-rich products to supply the dietary fiber intake as well as manufacturing bio-friendly and specific design films/coating in packaging industry; extracting bioactive proteins and potato protease inhibitors with high biological activity, and continue to build new commercial products based on potato protein and examine their health benefits. Noteworthy, the preservation methods play a key role in phytochemicals contents left in foods and potato performs superior to many common vegetables when meeting demand of mineral daily intake and alleviating mineral deficiencies.

Keywords: starchy food; potato protease inhibitors; phytochemicals; antioxidants; cancer prevention

1. Introduction

The position of potatoes on the table varies with the development of the region. In many developed countries, it acts as a vegetable with intakes vary from the lowest value in the UK of 102 g per capita to the maximum intake of 181 g per capita in Belarus per day for adults [1]. On the other side, especially in some rural areas of America and in the highlands of Latin American countries, potato is consumed a day for adults as much as 5-6 times of quantities in developed countries [2]. China ranks first in potatoes production and makes up about 24.53% of world production in 2018, which was deposited in the Food and Agriculture Organization of the United Nations database [3]. The potatoes have gained its fame as a globally consumed food crop in qualities mostly from its tremendous yield per unit area [4], affordability [5] and large daily consumption. Potato functions as an antioxidant, antibacterial, anti-inflammatory, anti-obesity, anti-cancer, and anti-diabetes in human and animal clinical studies [6]. Compounds existing in potatoes such as starch, protein, fiber, mineral, polyphenols, and carotenoids are thought to have a variety of benefits for human beings [6], although significant differences in the nutritional profiles and contributions of different potato cultivars to the human body. For whole potato tuber, the carotenoid concentration of yellow-fleshed potatoes is higher than that of white-or purple-fleshed potatoes, while the anthocyanin concentration of purple potatoes is higher than that of red or white-fleshed potatoes. Since polyphenols are mainly

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concentrated in peels, colored potatoes generally have higher anthocyanin and carotenoid concentration than whole white potatoes. The beneficial properties are attributed to the presence of these nutritional compositions.

However, with the increasing concern about weight and diabetes as well as other cancers, potato behaviors as carbohydrate-rich food and are generally considered to a high glycemic index and glycemic load [7,8], which routinely described have something to do with the risk of type 2-diabetes [8,9] and weight gain [10]. Hopefully, some studies support the prospective effects of eating potatoes on our overall health [11], even though a small minority of them claim that the consumption does not affect weight control or diabetes [6]. While some researches indicated that the consumption of potatoes has a direct association with an increase in hypertension [12] since potassium supplementation has a potential prevention effect on hypertension and chronic disease [13]. To our knowledge, hypertension is a major risk factor for cardiovascular diseases, especially coronary heart disease, stroke, and heart failure, as well as renal failure (WHO, 2004). This is the reason for the consumption of potatoes declined in the past few decades. To change the negative trend and alleviate grain shortage by eating potatoes in some areas, it is crucial to make it clear about the functions of nutritionally important components of potato tubers and what the factors should be first consideration while processed certain potatoes.

Before this review, there are a number of studies discussing the functional properties of potatoes, but they lack conclusive results about the main factors that have on those compounds. Thus, this review intends to summarize the factors that influence the changes in the main functional components of potatoes and discuss referred research focuses, then help to make it clear for further researchers to make efforts into. These recent researches have revealed possible directions for breeding programs and processed approaches to foster the functional composition of potatoes.

2. Potato starch and its functional properties

2.1. Structure of potato starch

Starch is a chief reserve carbohydrate for providing energy in potato tubers [14], which is a semi-crystalline biopolymer and consists of two major components: amylose and amylopectin. Native potato starch contains a large proportion of amylopectin nearly up to 70%. Amylose, with approximately 0.2% α-(1→6) linkages, exists as a long linear glucan, the molecular chain turns every 6 glucosyl units to form a helical structure [15] which can form a double helix by associating with another glucan chain. The established double helix is resistant to digestive enzymes [16] and therefore the proportion of amylase in starch affects starch digestion. Amylopectin, with about 5% of α-(1→6) linkages, shows a complex branch structure thereby is less likely to associate with other molecular. Thus, starch with a higher ratio of amylose to amylopectin prone to from gels than starch with a lower ratio, which is usually glue-like after heat-moisture treatment [17].

Base on the structure of two types of starch, starch with a high amount of amylase is not recommended in complementary feeding [17], but "high amylose" crops have been widely prevailing in the health food markets because high-amylose starch can enhance colonic fermentation, acting similarly to dietary fiber [18]. The properties of starch, to some degree, depending on the ration of amylose and amylopectin, they are also affected by the shape and size of starch granules. The utility and development of starch involve not only food processing but also papers, cosmetic, and textile industries et al [19].

2.2. Digestive properties of potato starch

The cooking process and storage condition can greatly influence the molecular properties, functional properties and digestibility of starch. For instance, uncooked potatoes are resistant to digestion, whereas cooked potatoes can be easily digested. Cooled potatoes are less digestible than warm cooked potatoes. It is vital to know the composition of starch in potatoes and choose proper processing and storage approaches to maximize the benefits. Starch digestion relies on its susceptibility to α-amylase and α-glucosidase (maltase) [20]. The digestion process is affected by the

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architecture of starch granules and the structure of glucan, as well as the interaction between starch and other compounds [21]. Digestible starch is the major glycemic carbohydrate providing energy and is given as the first complementary nutrients in many areas [17].

Resistant starch (RS) is a form of starch and gets the name for resisting digestion in the small intestine [22] but can be fermented by the colonic microflora in the large intestine [21,23]. RS as a functional ingredient normally derives from foods like bananas, potatoes, grains, and legumes, acting as a substrate for gut microbiome and deserving a great many health benefits for human beings [18,23]. Indigestible starch was reported can enhance markers of bowel health, like increasing short-chain fatty acids (SCFAs) levels [22,24]. As Wolfsdorf and Weinstein (2003) reported granular starches (uncooked starches) can be digested slowly and have the role of adjuvant therapy of some diseases, such as glycogen storage disease.

Potato starch, a B-type starch that has a smooth surface with no visible voids or pinholes [25], is classified as type-2 resistant starch [28] and less likely to vulnerable to a digestive enzyme [26]. The starch granules do not dissolve in cold water before being modified (eg, by cooking, chemical, or enzymatic modifications). Cooking with sufficient water initiates starch gelatinization, cooked starches digestion is determined by amylose content and amylopectin structure. The parameters of gelatinization vary with the source of the starch, potato starches can be gelatinized at a temperature higher than 60 °C [17].

The glycemic index is an indicator of the digestibility or glucogenesis of starchy food. Several in vitro methods were used to predict in vivo glycemic index [27]. A drawback of blood glucose measurement is that blood glucose is buffered by glyconeogenesis, with the result that the amount of dietary glucose generated from starch can't be accurately reflected [28]. To distinguish dietary glucose from total blood glucose, the isotope tracing methods of feeding 13C-labeled or 13C-enriched starchy materials were adopted [28].

In vitro Englyst assay has been commonly applied in the food industry. The method classifies as "rapidly digestible starch (RDS)," "slowly digestible starch (SDS)," and "resistant starch (RS), which causes argument from some researchers, such as Butterworth et al, who said that all starch molecules are digested at the same rate and there is no reason for the classification [29,30]. Besides, the Englyst assay doesn't take into account the interaction between starch molecules and mucosal α-glucosidases, the two have different digestion mechanisms, from that of fungal glucoamylase [29].

Make good use of starch in potato and properly prepare starchy foods are critical to clinical application. Starchy foods, especially amylopectin and modified starch can be applied to young children's diet as a complementary feeding [31]. More and more recent, numerous works for health reason were proposed, like using potato peel powder as a protein/fiber source to make the cake and by observing the quality of the cake, the baking test showed that potato peel flour can significantly enhance the cake aspect and quality, especially by substituting wheat flour with 10% potato peel powder, cake with less hardness and the brighter and more saturated brown-orange color was established [32]. The study gives us a fascinating insight and lets us find a new way out about developing fiber-rich cakes to supply the dietary fiber intake. Additionally, as carbohydrates are an important part of a post-exercise recovery meal, potatoes can be consumed to fuel glycolysis during and after activity. Moreover, potato starch can be applied to manufacture polymers. Actively, bio-friendly and natural-based materials are an innovative schedule for plastic processing plants and packaging manufacturers.

2.3. Potato starch and edible films

Starch, a natural polysaccharide, is one of the most commonly used materials for producing films or coatings. However, starch-based films are usually brittle and not resistant to water activity, which limits their application in packaging. To prepare starch-based films with good mechanical properties, water-resistant properties as well as anti-microbial properties, numerous works have been done. Especially, to protect and preserve fruits and vegetables, various starch-based composites (films or coating) were established and their anti-microbial properties were assessed. Bajer, et al. (2020) manufactured a novel biodegradable composite based on potato starch modified with chitosan, and

Aloe vera gel and glycerol as plasticizers were incorporated into the system. The composites showed good transparency, flexibility as well as thermal resistance. Meanwhile, the composite turned out to be more susceptible to the bacterial (Bacillus sp.) rather than to fungal (F. culmorum) activity [33]. Zhang, et al. (2019) suggested cooperation of mesoporous silica nanoparticles and cinnamon essential oil (CEO) into potato starch film markedly enhanced the tensile strength and physical properties of films, the films also had better antimicrobial activity against FJ09 species than against CNRMA 03.0371 strain [34].

By investigating the bio-composite films based on potato starch-glycerol-olive oil, incorporating with zein nanoparticles (ZNP), Farajpour et al. reported both olive oil and zein nanoparticles reduced water vapor permeability, and zein nanoparticles increased the mechanical resistance of the composite films [35]. The effects of different treatment methods including pullulanase debranching (PD), ultrasound treatment (UT), dimethyl sulfoxide heating (DSH)) on the physicochemical properties of potato starch (PS) and PS-based films were studied. The results showed that PS-LA composite films had higher tensile strength, lower elongation at break, and lower moisture permeability than native starch-based films, the films prepared by PD method had the highest tensile strength and lowest water vapor permeability among the tested films [36].

Some other researchers use potato husk starch to prepare edible films. For example, edible films that were fabricated from by-products, prickly pear peel mucilage (PPM) and potato husk starch (PHS) showed low water permeability (WP) [37]. On top of that, using agro-industrial wastes and exploring the applications in food packaging contributes to sustainable alternatives due to the recovery and reuse of the processing residues.

3. Potato protein as functional food ingredients

3.1. Potato starch and edible films

Potato protein is reported to have a high biological value, which is a measure of the proportion of protein from a specific food that can be used to synthesis the protein of the organism. Some indicators can exhibit the nutritional value or protein: such as the essential amino acids index (EAAI) and the chemical score (CS) [38]. The CS means making a comparison of each essential amino acid (EAA) in a specific protein to the content of a standard protein, typically whole egg. The CS of the EAAs and the EAAI can be calculated concerning the reference protein of the joint FAO/WHO (1991).

3.2. Amino acid composition of potato protein

EAAI and CS of EAA present in potatoes of different flesh color varieties are shown in Table 1. As shown in Table 1, potato contains plenty of aspartic and glutamic acids and their amides, also EAAs like leucine, lysine, phenylalanine, valine, and tyrosine [39]. Potatoes are one of the best plant sources of lysine [40], an EAA generally absent in grains. The main fractions of proteins present in the tuber are patatin, protease inhibitors, and other high-molecular-weight proteins [41]. They are associated with several health benefits such as lower allergic response [42], antimicrobial effects [43], antioxidant potential [44], and the regulation of blood pressure and blood serum cholesterol control [44,45] and anticarcinogenic behavior [46]. To compare with egg white, potato protein is of great biological and nutritional value, and it has a CS range of 57-69 [47], changing depending on the storage time and variety [38].

Table 1. Essential amino acid index (EAAI) and chemical scores of essential amino acids present in potatoes of different flesh colour varieties.

Variety	Essential amino acids									Limiting amino acids	
	EAAI	**Thr**	**Met + Cys**	**Val**	**Ile**	**Leu**	**Phe + Tyr**	**Lys**	**∑eaa**	**1st**	**2nd**
Blaue	79	71	63	93	92	63	118	65	81	Met +	Lys +

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Annelise										Cys	Leu
Blue Congo	86	76	59	114	102	63	134	79	91	Met + Cys	Leu
Herbie 26	96	82	78	125	112	72	134	88	79	Leu	Met + Cys
Rote Emma	110	93	78	146	129	88	165	101	116	Met + Cys	Leu
Vineta	82	82	63	103	89	63	115	75	85	Met + Cys	Lys + Leu
Fresco	118	115	92	154	122	84	182	102	123	Leu	Met + Cys
Protein standard (g/16 g N)		3.4	2.5	3.5	2.8	6.6	6.3	5.8	30.9	-	-

Note: Adapted from [38].

The amino acid profile in dry matter of potato was checked, saying leucine limits the quality of purple- and red-fleshed varieties while sulfur amino acids, methionine, and cysteine primarily influences yellow-fleshed cultivars [38]. The result consistent with the data published by Eppendorfer et al. (1994) who thought that methionine, cysteine and leucine were the most limited amino acids in the studied potato tubers [48], which is however in contrast to another report claiming that the sulfur amino acids were the limiting amino acids in all investigated potato varieties [49].

Peksa et al. surveyed the influence of storage conditions of potato on its amino acid composition, they concluded that with the increased storage time under certain conditions, the total protein and amino acid content declined. Most parts of the amino acid content decreased from 19 to 6% and from 38 to 21% after three and six months' storage, respectively. Nevertheless, the coagulable protein showed a rising tendency and increased by 25%. They also claimed that storage temperature did the effect on the coagulable protein content or serine, glycine, cysteine, tyrosine, and phenylalanine [38].

3.3. Fractions of potato protein

There are two key fractions of potato protein which can be treated with high nutritive value: coagulable protein (nitrogen compounds which can be precipitated by trichloroacetic acid) and nonprotein organic compounds (such as free amino acids). In particular, the coagulable protein is more valuable since its well-balanced amino acid pattern [50]. The total and coagulable protein content in the potatoes depended on the variety, not on the flesh color [38]. Different extraction techniques of tuber protein like precipitation methods (thermal and acidic precipitation, salt precipitation, ethanol precipitation, ammonium sulfate precipitation, carboxymethyl cellulose complexation), ion exchange, and separation of bioactive proteins and peptides have been explored to retain functionality and associated health benefits, and in turn, improve their potential application. The recovery of native protein from potato fruit water discharged from the starch factory has been commercially produced, in 2007, the Dutch potato starch group introduced the adsorbent processing platform with proprietary mixed-mode ligand chemistry in its subsidiary of Solanic to extract high-performance proteins for the food and pharmaceutical industries [51]. Jin, et al. [52] studied the effect of continuous polymer and pore phase known as Amberlite XAD7HP in lab-scale and pilot-scale on the recovery of potato protein from potato fruit water, this method resulted in an extract primarily composed of a large proportion of protease inhibitors.

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3.4. Potential applications of potato protein

Cardiovascular disease (CVD), as a major global crisis, has been arousing wide interests around the world. The schedule of control hypertension and prevent CVD is considered to use the angiotensin-converting enzyme (ACE) inhibitory to regulate blood pressure and cardiovascular function currently can be very promising [53]. Nowadays, even though several ACE inhibitors are available, we cannot ignore some side effects of them, like dry cough and angioedema [54]. Thus, nutraceuticals such as bioactive peptides will be a choice to replace those drugs, which can reduce the cost of drug therapy and are more safety [55,56]. Although few doubts remain, some food-derived peptides have been shown to have ACE inhibitory activity in vitro and many of them performed significant anti-hypertensive activity in rat studies [57]. The arguments arise because of different study designs and diverse methods of blood pressure, as well as a variety of genetic backgrounds of the study population [58]. Mäkinen et al. designed a schedule to check the effects of potato peptides (PP) and rapeseed peptides (RP) on blood pressure in vivo in the Goldblatt rat model of hypertension and showed that both the two peptides had the anti-hypertensive effects due to synergistic effects of several different ACE inhibitory peptide sequences in the samples [59]. According to current knowledge, more extensive researches focus on the practical application of food-derived bioactive peptides and on solving their not enough effective issue for replacing drug therapy in the actual treatment of hypertension. While other functional qualities of potato protein such as emulsification and foaming abilities should be taken into account since they can help broaden the application of potato in the food industry.

Potato protease inhibitors have several potential applications, such as treatment for weight loss, periananl dermatitis, infections, thrombotic disease, and cancer. Previous research showed that potato protease inhibitors can elevate plasma cholecystokinin levels which influences food intake [60,61]. This gastrointestinal hormone is involved in satiety and food intake regulation as well as blood glucose control in humans, and its increased levels in plasma delay gastric emptying, including feelings of fullness and reduce food intake. Most noteworthy, the Slendesta (a natural potato protein with 5% protease inhibitor P12) was found that can enhance the feeling of fullness without any side effect. When food is eaten, a factor appears in the gut that is absorbed by the small intestine. The small intestine then releases a signal molecule called CCK into the bloodstream. CCK travels through the bloodstream to various digestive organs and to the vagus nerve which signals the brain to produce feelings of fullness and satisfaction. A clinical study showed it can help people manage hunger and then achieve the goal of healthy weight management. Consuming 300 mg Slendesta (contain 15mg P12) before diets have a-day effect on dietary intake since P12 helps to increase CCK level and causing, prolong feelings of fullness [62–64]. Slendasta has been produced by an American company KEMIN, as a successful commercial product of controlling weight provides new insight into solving obesity. Due to the potential allergenicity of animal protein in susceptible subjects, it has gained much attention that using plant-derived proteins as a wine fining agent.

Patatin P is the name of a family of glycoproteins that can be recovered from potato aqueous by-product. It has been proved that Patatin is a suitable alternative to animal proteins used as a fining agent since it can reduce the total phenolics and tannins, as well as it can diminish astringency and the content of red wine phenolics able to react with salivary proteins [65].

Potato tuber proteins also can inhibit human fecal proteolytic activity efficiently, which opens up the possibility of using potato protease inhibitors to prevent and treat the disease. Potato carboxypeptidase inhibitor has been seen as a potential fibrinolytic agent for treatment and prevention of thrombotic disease for it can inhibit plasma carboxypeptidase activated thrombin-activatable fibrinolysis inhibitor [66–68]. Besides, Blanco-Aparicio et al (1998) showed that potato carboxypeptidase inhibitor competes with epidermal growth factor for binding to the receptor and has antitumoral properties; the epidermal growth factor receptor signal transduction pathway plays a prominent role in the development of carcinomas [69]. Potato tuber protease inhibitors also interfere with hydrogen peroxide formation [70], and processes resulting from solar UV radiation [71]. A series of antimicrobial Kunitz-type serine protease inhibitors (AFP-J, PT-1, Potide-G) have recently been isolated from potato tubers. As showed that AFP-J has potent antifungal activity against human

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fungal pathogens, eg., Candida albicans, which is the most common cause of candidiasis [72]. PT-1strongly inhibited pathogenic microbial strains, including C. Albicans, the plant pathogenic fungus Rhizoctoniasolani, and the plant pathogenic bacterium Clavibacter michiganese [73]. Potide-G potently inhibited the growth of various human or plant pathogenic bacterial (Staphylococcus aureus, Listeria monocytogenes, Escherichia coli, C. michiganense) and fungal (C. Albicans, R. solani) strains, and has also potent antiviral activity against potato virus Y infection [74]. According to current knowledge, more extensive researches focus on the practical application of food-derived bioactive peptides and on solving the not enough effective issue for replacing drug therapy in the actual treatment of hypertension. While other functional qualities of potato protein such as emulsification and foaming abilities should be taken into account since they can help broaden the application of potato in the food industry. Potato protease inhibitors have several potential applications involving treatment for weight loss, peri-ananl dermatitis, infections, thrombotic disease, and cancer. Previous research showed that potato protease inhibitors can elevate plasma cholecystokinin levels which influences food intake [60,61]. This gastrointestinal hormone is involved in satiety and food intake regulation as well as blood glucose control in humans, and its increased levels in plasma delay gastric emptying, including feelings of fullness and reduce food intake.

4. Potato phytochemicals and nutritional potential

4.1. Functional phytochemicals in potato

Potatoes are an excellent source of antioxidants, which mainly including carotenoids, anthocyanin, phenolic compounds, and vitamin C. Nutritionally, these compounds play a role in preventing cancer and heart attacks with the potent antioxidative properties [75]. Carotenoids accumulate in many plants, giving yellow, orange, and red colors. The color of yellow potatoes is due to carotenoids, which present high concentration in yellow cultivars, while in red- or purple-flesh potatoes where the color may be masked by anthocyanins. Carotenoids are primarily lutein, zeaxanthin, and violaxanthin, all of which are xanthophylls, presenting in the flesh of potatoes. The composition of tuber carotenoid varies with cultivars, however, violaxanthin and lutein usually are the most abundant proportions.

4.2. Carotenoids and health benefits

The quantities of total carotenoid in vegetables vary among cultivars and range from 0.038 (potato) to 17.31 (spinach) [76], mg/100 g FW, whereas in potato, the value range from 0.038 to 2.00 mg/100 g FW [77–79]. Among all the fresh fruits and vegetables analyzed, some certain potatoes (2.00 mg/100 g FW) [80] have a comparable value with other vegetables, like cabbage (0.25 to 0.43 mg/100 g FW) [76], strawberry (0.96 to 3.30 mg/100 g FW) [81] and tomato (1.63 to 8.57 mg/100 g FW) [82,83].

The carotenoids concentration in colored flesh potatoes is shown in Figure 1. The content of carotenoids presents 38.1-265μg /100 g FW in white-fleshed varieties and 107.5-260.3μg /100g FW in yellow-fleshed cultivars to 567μg /100g FW in yellowish-orange cultivars, some dark yellow-fleshed cultivars even have a carotenoids content as high as 2000μg /100g FW (As shown in Figure 1). Among all the various colored fresh cultivars, yellow-fresh varieties have the highest carotenoid content, followed by cream and white. Besides, as shown that over 100 cultivars grown in Ireland and Spain had carotenoid content from trace amounts to 28 μg/g DW in the skin and 9 μg/g DW in the flesh [84,85]. The lipophilic extract of potato with total carotenoids ranging from 35 to 795 per 100 g FW flesh shows 4.6-15.3 nmoles α-tocopherol equivalents per 100 g FW of oxygen radical absorbance capacity (ORAC) values [86].

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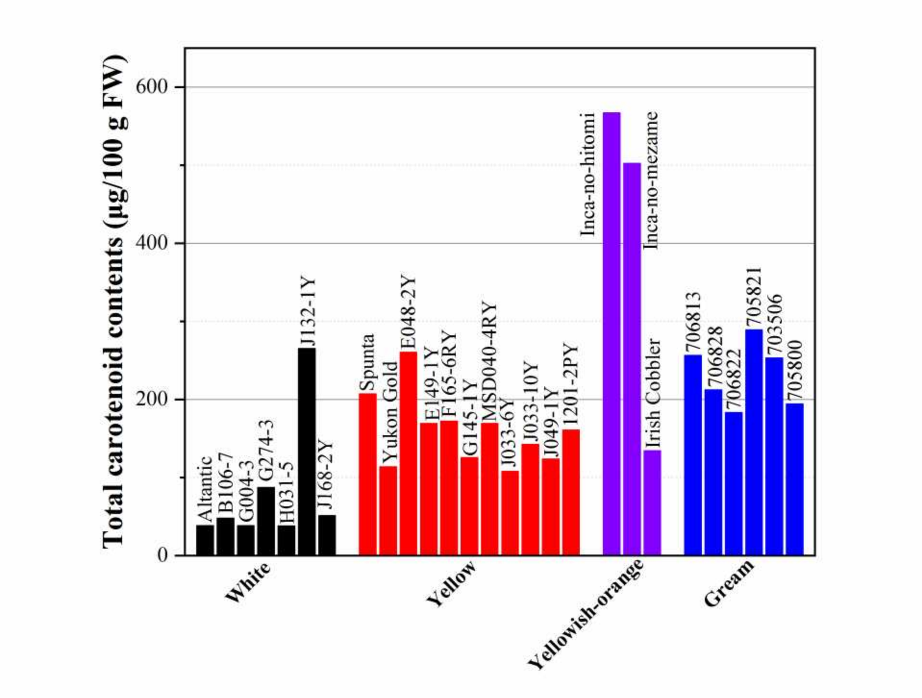

Figure 1. Total carotenoid concentrations by spectrophotometry and HPLC in potatoes.

Furthermore, potato as a staple food is most commonly consumed and has the most intake every day than other selected vegetables. That is to say, potato can be a key and more accessible carotenoid supplement in our daily life. Potato is not an origin of pro-vitamin. However, carotenoids can have provitamin A activity and thus can decrease the risk of several diseases [87,88], age-related macular degeneration, and the onset of cataracts [89–91]. The process of carotenoid accumulation is the result of biosynthesis, degradation, and stable storage of synthetic products [92,93].

Multiple factors control the broad diversity of carotenoid composition and content in storage tissue. Regulation of the catalytic activity of carotenoid biosynthesis can be a key and practical control for the final carotenoid accumulation. Phytoene synthase (PSY) is the rate-limiting step in the carotenoid biosynthetic pathway and manipulation of PSY expression in many plants has been demonstrated to enhance carotenoid synthesis by directing metabolic flux into the carotenoid biosynthetic pathway [94–96].

Carotenoid cleavage dioxygenases (CCDs) catabolizes enzymatic degradation of carotenoids. Expression of these genes inversely regulates carotenoid accumulation [97,98]. LCY-b and LCY-e can manipulate the synthesis of α-carotene and β-carotene respectively. The tissue-specific expression of carotenoid biosynthesis genes in potato is marked in red color in Figure 2. Some measures like traditional breeding and metabolic engineering approaches have been used to prove the tuber carotenoid. Traditional breeding can increase carotenoids based on broad-sense heritability of carotenoids [99]. Y locus can largely determine the tuber fresh color and zeaxanthin synthesis, encoding a β-carotene hydroxylase [100,101]. Molecular analysis identified a QTL on chromosome 3 that accounted for up to 71% of the carotenoid variation that was probably an allele of β–carotene hydroxylase, and several additional alleles affecting carotenoid amounts have been identified [102,103]. Multiple transgenic approaches have achieved a big success in increasing tuber carotenoids. Overexpressing bacterial phytoene synthase increased total carotenoids from 5.6 to35 µg/g DW, lutein increased 19-fold and β-carotene increased from trace amounts to 11 µg/g DW [96]. Furthermore, a study showed that the overexpression of three bacterial genes Desiree caused a 3600-fold increase in β-carotene to 47 µg/g DW, a 30-fold increase in lutein and a 20-fold increase in total carotenoids, producing a “golden potato” [104]. Manipulating the vitamin A pathway can fulfill 42% of the daily requirement for vitamin A (retinal activity equivalents) and 34% of the vitamin E daily requirement by consuming a modest 150 serving of boiled potatoes [105].

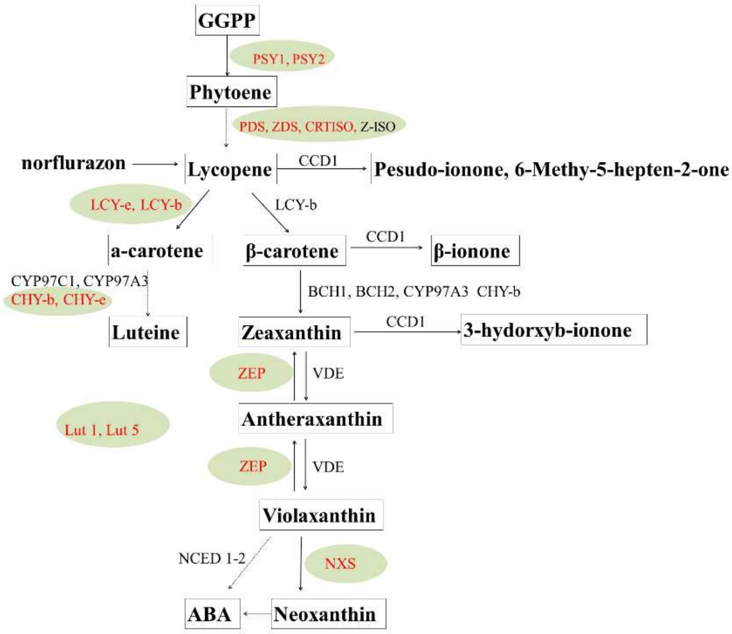

Figure 2. Biosynthesis, metabolic pathway and gene regulation of carotenoid compounds in potatoes.

4.3. Phenolic compounds and antioxidant activities

Potato supplies considerable phenolic compounds, which are concentrated in the peel and adjoining tissues [106]. The predominant one is chlorogenic acid (CGA) and consists of about 80% of the total phenolic acids. Red- and purple-flesh potatoes typically contain greater amounts of CGA than white potatoes. CGA may have a potential effect on lowering the risk of type 2-diabetes and slowing the entry of glucose into the bloodstream [107]. CGA in potatoes is synthesized via hydroxycinnamoyl CoA: quinatehydroxycinnamoyltransferase [108,109]. The R2R3 transcription factor StAN1 appears to mediate CGA expression, in addition to regulating anthocyanins [110]. Phenylpropanoid (phenolic acids, flavonols, and anthocyanins) content varies markedly among cultivars, somehow has a relationship with the genetic diversity [111]. Andean potato landraces have about an 11-fold variation in phenolic acids and flavan-3-ols, and a high correlation between phenolics and total antioxidant capacity [112–114]. Chilean landraces had 8- and 11-fold more phenylpropanoids than Desiree or Shepody, two common cultivars [115]. Phenolic content extracted from potato peel has been reported to have an antioxidant-mediated protective effect in erythrocytes against oxidative damage. However, polyphenols preservation is one of the keys to the quality of potato, concerning their flavor induction (astringency) and capacity to cause discolorations, such as enzymatic browning reactions [106]. Since most potato phenolics except anthocyanins are colorless, thus they present in white- and yellow-fleshed cultivars, which are desirable culinary materials in many countries. Total phenols/ Total phenolic content (TPC) in a variety of plant cultivars as obtained from Folin-Ciocalteau reagent (FCR) or HPLC was shown in Table 2.

Table 2. Total phenols in variety of plant cultivars as obtained from Folin-Ciocalteau reagent (FCR) or HPLC.

Variety / plant cultivar	FCR		HPLC	
	g GAE/kg FW	g GAE/ kg DW	mg/100 g FW	mg/100 g DW
Cauliflower	0.57-2.55	5.60-29.13		30-217
Cabbage	1.70-2.53	1.90-26.29	0.50	125-387

Broccoli	0.96-3.76		1.10-1.14	1173
Spinach	0.50-2.34	11.8		
Carrot (orange & black)	0.16-10.29	1.10-1.90	0.30-39.76	
Brinjal	0.82-2.92			
Green bean	0.78-4.58		17.10-66.3	
Mushroom	0.09-1.80			
Tomato	0.14-2.91		26.57	
Strawberry	0.99-3.05			
Blueberry	2.20-7.53			
Kiwifruit	0.80-0.96			
Pea		0.80-1.20		
Brussels sprouts				147
Italian kale				1127
Potato	0.31-8.83	4.48-11.19	23.2-67.4	260-2852

By reviewing plenty of researches, we found it hard to make a comparison between various vegetables since different methods were used previously. Thus, the review summarizes phenolic content in various plants measured by commonly used methods of Folin-Ciocalteau reagent (FCR) or HPLC and expressed with fresh weight and dry weight to provide a reference for next further study. By checking total phenols of plants determined according to the Folin-Ciocalteu (F-C) colorimetric method with expressing as a gram of gallic acid equivalents (GAE) per kilogram of fresh weight basis(g GAE/ kg FW), Potato (0.31 to 8.83 g GAE/ kg FW) offers comparable value to some certain vegetables and fruits, such as carrot (0.16 to 10.29 g GAE/ kg FW), blueberry(2.20 to 7.53 g GAE/ kg FW), and is superior to some cultivars, such as cauliflower(0.57 to 2.55 g GAE/ kg FW), cabbage(1.70 to 2.53 g GAE/ kg FW) as well as strawberry(0.99 to 3.05 g GAE/ kg FW). Besides, as expressed by a dry weight basis, potato (4.48 to 11.19 g GAE/ kg DW) can provide almost the same quantity of total phenols as spinach. According to the maximum total phenols intake (based on a gram of gallic acid equivalents per kilogram of fresh weight) from plant cultivars, if 200g potato were consumed every day, the total phenols that potato ensures should be provided by 700g cabbage or cauliflower, 170g carrot, 580 g strawberry or 970 g mushrooms, if 200g potato were consumed every day, the total phenols that potato ensures should be provided by 700g cabbage or cauliflower, 170g carrot, 580 g strawberry or 970 g mushroom. Otherwise, according to the data obtained from the HPLC method, total phenols of potato range from 23.2 to 67.4 mg/100g FW or260-2852 mg/100g DW, are similar to the green bean (17.10 to 66.3 mg/100g FW). While according to data of the Singapore Chinese population aged 45-74 years were obtained from Singapore Chinese Health study from 1993 to 1998, daily intake of potato is 6.9 g with 4.1 mg GAE/ day of TPC. In conclusion, the potato should be a lower-cost alternative for daily total phenols intake than other vegetables and fruits, especially, in some development areas, it can be the first consideration for antioxidants supplies.

4.4. Flavonoids and healthcare functions

The flavonoids, containing two leading constitutes-catechin and epicatechin, in the flesh of white potato is as high as 30 μg /100 g FW, almost twice of red- and purple-fleshed potatoes [86]. One group suggested that flavonols increased in fresh-cut tubers up to 14mg/100g FW and though they can be a valuable dietary source because of the large number of potatoes consumed [116]. The content of flavonols varies by more than 30-fold among different potato genotypes and there is even sizable variation within the same genotypes. Interestingly, potato flowers can synthesize a 1000-fold higher amount of flavonols than tubers which contain only micrograms per gram amount of flavonols [117] Several studies show that quercetin and related flavonols have multiple health-promoting effects,

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including reduced risk of heart disease; lower risk of certain respiratory diseases, such as asthma, bronchitis, and reduced risk of some cancers including prostate and lung cancer [118].

Colored potatoes are rich in anthocyanins that heavily exist in the skin of the potato, or partially or entirely derived from the flesh. Anthocyanins are natural colorants belonging to the flavonoid family [119]. The compounds are responsible for all the visible colors ranging from red to blue of fruits, vegetables, flowers, and roots. The most common anthocyanidins in plants are delphinidin, cyanidin, petunidin, peonidin, pelargonidin, and malvidin [120]. Anthocyanin-rich foods have proved an important role in the prevention of several types of human cancer, such as colon, breast, prostate, oral and stomach cancers [121], while showing no toxic effects on normal human cells [122]. Total anthocyanins of selected fruits and potatoes are shown in Figure 3. Unpeeled potato with totally pigmented the flesh can collect up to 527.4 mg/ kg FW of total anthocyanins. Red- or purple- flesh with skin can be a profitable source of anthocyanins, is similar to cranberries, and is superior to red cabbage [38]. As shown in Figure 3, the purple-flesh potato has a higher total anthocyanin content than red-flesh cultivars, ranging from 65.5 to 527.4 mg cyanidin /kg FW, while the value is 142-250 mg cyanidin /kg FW in red-flesh potato. Compare to blueberry (1694 mg cyanidin /kg FW) and strawberry (1171 mg cyanidin /kg FW), which are known as high-anthocyanin food, some varieties of potatoes are hopeful and have the potential to meet the demand of anthocyanins in daily life. What most noteworthy is that potato is a more accessible food and is consumed largely than strawberry and blueberry since the high cost and season limitation in eating those fruits. Trough investigating over 50 colored-fleshed cultivars, researchers found that the anthocyanins vary in the range of 0.5-7mg/FW in the skin and up to 2mg/g FW in the flesh [123].

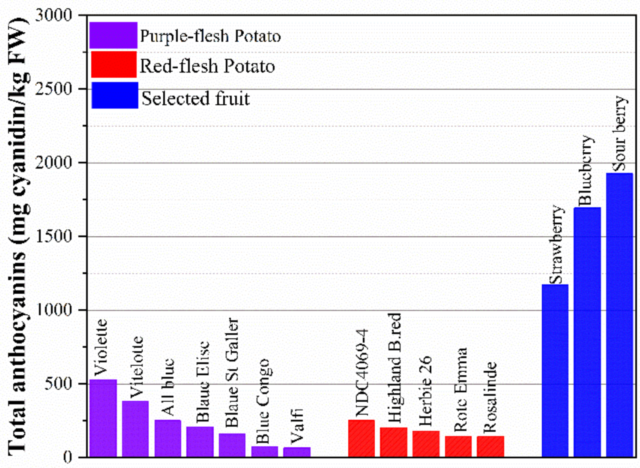

Figure 3. Total anthocyanins (mg cyanidin /kg FW) of selected fruits and potatoes.

The issue that arises to our attention is that high anthocyanin potatoes, usually with colored skin, are not as widely consumed as white or yellow potatoes. Tuber anthocyanin in the periderm is regulated by at least three loci, D, P, and R [124–126]. Biochemical and expression analysis identified an AN1 transcription factor complex involved in potato anthocyanin synthesis [127,128], and global expression studies using microarray and RNA-seq analysis of white and purple potatoes have identified various transcription factor variants, including a ten amino acid C-terminalmotifonAN1 required for optimal anthocyanin synthesis [129–131]. SSR markers for anthocyanin biosynthesis can be a technique for potato breeding programs [132]. Purple-flesh potatoes known as a high-phenolic cultivar has been proved to benefit health with anti-cancer properties [133–136] and amelioration of chromium toxicity [137]. Observed by a mouse model, anthocyanins from purple potatoes showed

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an effect of attenuating alcohol-induced hepatic injury [138]. In a human feeding study adults fed 150g of purple potatoes a day for six weeks, results showed that inflammation and DNA damage decrease [139]. Another small human trail suggested people who have an average of 54 years old consumed purple potatoes and had a significant drop in blood pressure and without weight gained [140]. Also, postprandial glycemia and insulinemia were observed to have a downward trend in males fed purple potatoes [140]. A previous study demonstrated that potato with high polyphenol content was inversely associated with their glycemic index [141]. For rats fed an obesity-promoting diet, purple potatoes promised metabolic and cardiovascular benefits [142].

4.5. Vitamins and nutritional potential

4.5.1. Vitamin C

When it comes to the bioactive compounds in potato, we cannot ignore the vitamin C, which has received the most attention. Vitamin C can be synthesized in the tuber part of the potato, and also be transported from leaves and stems and then be accumulated here [143,144]. Potato generally contains 20 mg /100 g FW of vitamin C, which may account for up to 13 % of the total antioxidant capacity. The vitamin C recommended intake per day for women (18-60 years old) is 60 mg. Potato (16.10 to 34.80 mg/100 g FW) [145,146] is a much better vitamin C source than cabbage (5.27 to 23.50 mg/100 g FW) [147,148] and even some kinds of tomato (8.26 to 22.54 mg/100 g FW) [149]. It should not be ignored as a crucial nutrient supplement based on vitamin C intake. Plus, in terms of the consumption rate and economical concern, as well as the storage condition for vegetables, the potato could be the best choice for humans. As deficiency of iron has been a global problem, the consumption of potato with high Vitamin C content might be a way to solve the problem.

Based on some researches, the content of Vitamin C is not only influenced by the varieties, but also by area and time of planting [150,151]. Many efforts should be focused on maintaining Vitamin C level in cold storage since loses of up to 60% have been observed after cold storage [152,153]. By examining the Vitamin C content in 12 potato genotypes after storing for two, four, and seven months, a substantial loss after four-month storage occurred, but several showed no significant loss after two months [154]. While this contrast markedly with a report about Vitamin C increased as many as several-fold in 11 Indian potato varieties after storage [155]. It is highly desirable that finding a cultivar show no loss after at least two months of storage. Other studies mentioned that compare with the effect of storage temperature on Vitamin C, atmospheric oxygen levels function greater [155].

Cares should be seriously taken during processing because almost half the Vitamin C was lost during pre-freezing, which can be actually avoided [156]. Therefore, to optimize processing and choose proper methods to preserve crops is a practical measure to reduce the loss of vitamin C. Also, crop management plays an important role in maximizing vitamin C, say utility of high nitrogen fertilization result in reducing vitamin C amounts, followed with a more rapid loss when storage of the cut product [157]. Consumers can choose potatoes with the peel to maximize phytonutrient intake. This theory proposes challenges for the food industry about how to improve the appearance and taste of the potatoes so that they can accept widely, also about how to use the waste generating during processing and get more natural products, including antioxidants [158–160].

According to some studies, the hydrophilic antioxidant activity of totally pigmented red or purple potato is comparable to brussels sprouts or spinach. The total anthocyanins range from 9 to 38 mg/100 g FW and ORAC varies from 7.6 and 14.2 μmole/g FW of Trolox equivalents. Meanwhile, potato generally contains 20 mg /100 g FW of vitamin C, which may account for up to 13 % of the total antioxidant capacity. The total antioxidant activity (TAA) of potatoes was estimated using the ABTS radical cation method and the DPPH assay is presented in Figure 4. It can be concluded from the figure that purple-fleshed potato has the highest total antioxidant activity among the selected colors with a range of 251 to 1497.6 equivalent ascorbic acid in mg/kg FW, following by pink (860.3-948.6 equivalent ascorbic acid in mg/kg FW) and red (316.9-424.4 equivalent ascorbic acid in mg/kg FW). Which means colorless cultivars, including white-fleshed ones and light yellow-fleshed potato

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generally have a relatively low antioxidant activity, might be responsible for low vitamin C and anthocyanins and even phenolic compounds content.

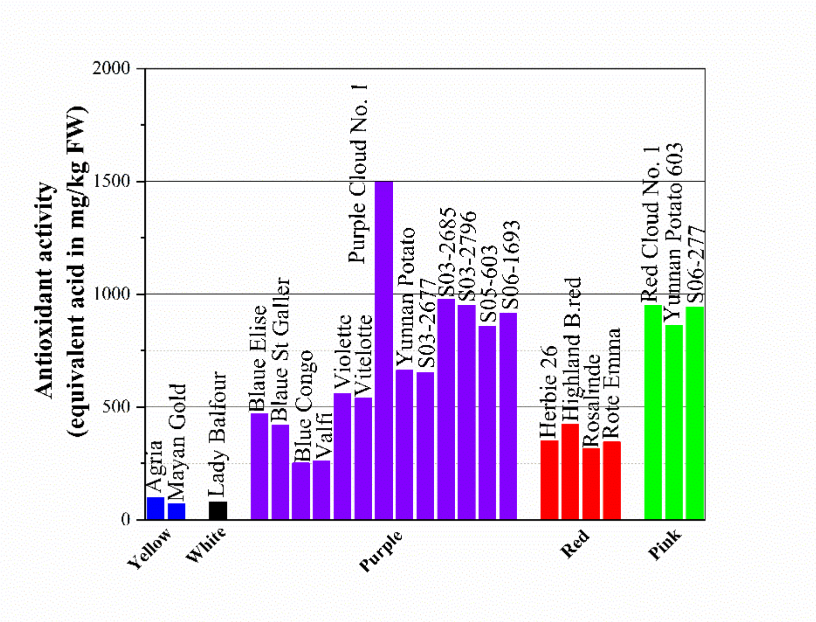

Figure 4. The total antioxidant activity (TAA) of potatoes was estimated using the ABTS radical cation method and DPPH assay.

Some other studies demonstrated a reverse effect of phytochemicals on various diseases (e.g., chronic inflammation, cardiovascular diseases, cancer, and diabetes) [161]. Many of the compounds discussed above are present in higher concentrations in immature potatoes. This is because certain tuber nutrition contents decrease as the growth of the tuber. Baby potatoes (with golf ball size) have the amounts of phenylpropanoids as many as 3-fold of mature potatoes of the same cultivar, and higher amounts of carotenoids and various other phytonutrients [162]. CGA content decreased 39-72% during development and varied among cultivars [162].

By investigating the effects of domestic cooking methods (boiling, baking, steaming, microwaving, frying, stir-frying, and air flying) on the composition of phytochemicals (phenolics, anthocyanins, and carotenoids) in purple-fleshed potatoes, reduction of the vitamin C, total phenolic, anthocyanin, and carotenoid contents were observed after cooking. Among these changes, the decrease of antioxidant activity was responsible for a reduction in the total phenolic content. The loss of vitamin C and phytochemicals was caused by frying methods but not alter the antioxidant activity, which is likely due to the prevention of by-products of the Maillard reactions. It should be noted that steaming and microwaving have the potential to be used as a measure to retain phytochemicals and antioxidant activity [163]. Xu, et al. (2009) also conclude that all cooking methods (boiling, baking, and microwaving) caused a decrease in antioxidant activity and phytochemical concentration in potato [164]. While according to the report of Blessington, et al. (2010), baking, frying, and microwaving can significantly increase the total phenolic content, chlorogenic acid content, and antioxidant activity in potatoes [165]. And Faller and Fialho (2009) showed that despite a significant increase in the total phenolic content, the antioxidant activity of potatoes decreased [166], whereas Burgos, et al. proposed that boiling has a positive effect on enhancing the total phenolic content and antioxidant activity and has an obvious reverse effect on the total anthocyanin content. The difference might be attributed to the different cultivars and pretreatment methods and cooking conditions, as well as the nonuniformity of analytical methods used [167]. More importantly, anthocyanin usually is unstable and can be significantly influenced by different pH [168]. Therefore, more systematic studies of the effects of processing and cooking methods on phytochemicals, especially the function such phytochemical compounds have on various diseases.

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4.5.2. Vitamin B9

Folate (Vitamin B9) deficiency is a worldwide concern that has a connection with birth defects [169]. Potatoes can be a source of dietary folate, providing 7%–12% of the total folate in Dutch, Finish, and Norwegian diets [170]. Increased consumption of potatoes can help to reduce the risk of low serum folate concentrations [171]. Folate concentrations in potatoes have been examined, the content is significantly different, and with a range of 12 and 41 μg/100g FW and 0.5–1.4 μg/g DW among cultivars. Some wild species, like S. Boliviense, contain 115 μg/100 g FW of Folate [172–174].

4.5.3. Vitamin B6

Vitamin B6 is indispensable in a wide range of metabolic, physiological, and developmental processes and shows a high concentration in potatoes. The USDA's Supertracker website released a medium potato that can provide 48% of the supplement of Vitamin B6. Vitamin B6 deficiency can contribute to numerous health issues, including diabetes, neurological, and skin disorders. The maturity of the potato has something to do with the degree of Vitamin B6. According to the report by Mooney et al, vitamin B6 ranged from 16 to 27 μg/g DW in immature and mature tubers [175]. Also, there is a small proportion of thiamine (vitamin B1) in potatoes with a concentration of 0.06–0.23 μg/ 100 g FW [173,176]. Thiamine content as a moderate broad-sense heritability, suggesting that breeding program can be the first consideration for increasing the level [177].

5. Potato Minerals and health benefits

5.1. Potassium

Potato is also well known to be a provider of potassium, copper, phosphorous, iron, zinc, magnesium, and manganese. This makes itself an indispensable candidate for contributing to the alleviation of mineral deficiencies caused by dietary constraints. Especially, for potassium supplement, potato behaves extremely well. The content of potassium in potatoes is higher than bananas, a well-known potassium source (SR28 2016). Potassium content increases during the entire growing season of potato [178]. The range of potassium content in potato is about 3.0–8.2 mg/g FW [14,179,180]. Contents (mg/100g) of certain macro- and microelements in edible parts of a variety of plant cultivars in comparison to recommended intakes are presented in Table 3. As we conclude, potato as a potassium source containing potassium in range of 104-540 mg/100g FW and is superior to partial vegetables, even has a comparable quantity with banana which is known as a high-potassium food. Consumed potato together with cabbage, cauliflower, spinach, or even cow milk can promise the recommended daily intake of potassium which is about 3.1g for an 18-60 years old woman. In a study carried out in the Pacific Northwest, the potassium content for breeding lines and established varieties was between 19-25mg/g DW. Broad-sense heritabilities (H) were 0.33 and 0.81 for the Tri-State russet skin varieties and Regional Red/Specialty varieties [181]. A survey of wild tuber-bearing Solanum species in the Commonwealth Potato Collection showed a range of 15–27 mg potassium /g DW [182].

Table 3. Contents (mg/100g) of certain macro- and microelements in edible parts of variety of plant cultivars in comparison to recommended intakes (mg/100g FW).

	Macro-elements				Micro-elements	
	K	Ca	Mg	P	Fe	Zn
Recommended intake/day	3.1 g	800mg	280mg		12-18mg	7mg
Banana	261-546	0.35~1.35	80.0~84.0	/	17.15~47.19	0.34
Cauliflower	389-705	6.33	5.00	/	0.29	0.12
Broccoli	405-727	8.87-11.40	5.9	/	0.26	0.87

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Spinach	210-630	98.0-241.39	11.1-85.0	/	3.90-9.49	0.2-0.55
Pepper	159-244	8.8-13.9	11.2-18.8	17.6-37.6	288-975	270-775
Cabbage	165-340	70-152	12.0-42.0	32	1.4-1.7	0.3-0.5
Carrot	357	25	71.0	/	9.28	1.28
Strawberry	153-312	7.6-29	11.0-23.4	0.5-24	0.20-0.62	0.14-1.5
Cow milk	152	122	12.0	119	0.08	0.530
Kiwifruit	254-300	15.4-26	11.0-13.1	24-25	0.19-0.25	0.09-0.14
Potato	104-540	4.98-21.29	13.7-41.9	30-60	0.34-1.80	0.27-0.53

The interaction between sodium and potassium can maintain the balance of blood pressure, reduce the risk of heart disease, strokes, and kidney stones, and guarantee normal heart rhythms. The potassium in potatoes is also vital for helping muscles contract. Meanwhile, a study demonstrated that potassium deficiency correlates with the hardening of the arteries [183]. Some estimate claims that only 2% of Americans intake enough potassium. Potassium deficiency has been proposed as a public health concern in the 2015–2020 Dietary Guidelines for Americans. The average adult intake is about half of the Institute of Medicine's recommendation of 4700 mg/day [184]. Storey and Anderson (2016) surveyed average nutrient intakes as well as total vegetable and white potato (WP) consumption among children aged 1–3 years using day 1 dietary data from the NHANES 2009–2012 and the Food Patterns Equivalents Database 2009–2012 and concluded that average intakes of most nutrients, including calcium, were exceeded Dietary Reference Intakes (DRIs), but the average intakes of potassium, dietary fiber (DF), and vitamin D were 67%, 55%, and 49% of DRIs, respectively. Looking for excellent sources of potassium and DF, such as potatoes, is an urgent need today [185]. The final content of most minerals of potato relies on whether removing the skin, and the way of processing, preparation, and cooking such a material [14,186–188]. The USDA nutrient database typically lists baked potatoes within 5.5mg/ g FW and a potato that contains 8.2mg/g FW would provide ~50% more potassium. Selecting the fine genetic capacity of producing higher amounts of potassium is expected to be on the agenda. The potassium in potato tuber increased throughout the growing season as a report reveals [189]. Some factors, like the environment as well as the crop management, can affect the tuber potassium content, for example, drought condition was found to increase K about 12% [190].

5.2. Iron

Nearly two billion people worldwide have been suffering iron deficiency and are one of the most widespread nutritional deficiencies of all according to the World Health Organization (WHO), which calls it a "public health condition of epidemic proportions" [191]. Potatoes contain modest amounts of iron, which should be readily bioavailable because of its lower phytic acid content than other crops. Considering the high broad-sense heritability estimates up to 0.73 for potato, developing new cultivars with higher amounts of iron should be achievable [192,193]. A range of 17-62 µg / g DW was presented in an investigation about potatoes grown in the Pacific Northwest, Colorado, and Texas [192]. Some varieties were reported to have a rather wider range of 0.3-2.3 mg Fe/g FW [194]. As shown in Table 3, the amount is 0.34-1.80 mg/100g FW in potato. The iron content of some Andean germplasm is comparable to amounts in rice, maize, and wheat [195].

5.3. Magnesium

Magnesium is another mineral necessary for the human body. Couples of studies showed that increased magnesium intake may help to inhibit diabetics, one of the most widespread and costly diseases [196]. The RDA for adults ranges from 310 to 420 mg. It is estimated that nearly 70% of American adults lack Mg, and the other 20% of them consume less than half of the recommended amount of magnesium. Mg deficiency is associated with higher levels of inflammation and cardiovascular risk [197]. Potato magnesium levels were reported to range from 142 to370 µg/g FW

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[198,199] and 0.9–1.1 mg/g DW. However, the magnesium content in potato showed in Table 3 is 13.7-41.9 mg/100g FW. The content is almost equal to the quantities in cabbage. The cultivated area of potato could be a factor that decides the content of Mg. In the Pacific Northwest, Colorado, and Texas, the magnesium content of potatoes ranged from 787 to 1089 μg /g DW [200]. In the Tri-State and Western Regional russet skin trials and the Red/Specialty trials, the broad heritability (H) was 0.57, 0, and 0.72 respectively. Crop nutrient management was reported to have different effects on Mg. As showed it can affect Mg rather than K [201], while another study found little effect of fertilizer on Mg. In addition to the minerals discussed above, some other minerals in potato were also examined [202–204].

5.4. Phosphorus

Other than potassium, there is another main mineral present in the tuber-phosphorus. It plays a crucial role in the human body. Inadequate phosphorous intake results in abnormally low serum phosphate levels, which result in loss of appetite, anemia, muscle, and tingling of extremities, and difficulty walking. According to the daily requirement of phosphorus is 800-1000mg. While in potatoes, phosphorus ranges from ~1300 to 6000 μg/g DW [178,203,205] and 30-60 mg/100g FW (shown in Table 3). A study informed us that the fertilizer P applied together with nitrogen resulted in the phosphorus increase in potato parts, but without a significant impact on the yield of tubers [206]. However, potato combines a high P-demand with low P uptake [207], thus a large amount of P needed to plant potatoes. Apart from improved management practices aiming at the reduction of P losses to the environment and closing nutrient cycles, new cultivars with higher P efficiencies may contribute to more sustainable use of P resources.

6. Conclusion

As the story of potatoes in the human diet continues to evolve, new and advanced techniques will promise significant opportunities to further explore the role of potatoes and their functional properties. Both in Asia and Africa, the potato production has boomed, especially in China where the potato production is by far the largest and has made potatoes as its forward-looking food security strategy, whereas the production in the West has declined. With the characteristics of ease of cultivation, minimum transportation and storage condition, and rich in carbohydrate, vitamin, and antioxidants, potato as a stable food still has much space to be examined. Remarkably, on the other hand, potato contributes only 440 calories per pound, which makes it a promising healthy food source to meet today’s requirements of dieters. Potato starch has some unique properties compared with cereal starches. The most significant ones involve long amylopectin chains forming hydrated and ordered B-type crystallites of tuberous starch. To date, certain details regarding the structure of potato starch remain unclear. Thus, more efforts should focus on the actual model of the interconnection of the cluster units of the amylopectin component and the connection between the proposed superhelical structure and the blocklet structures in the granules. And genetic engineering can be a possible solution to help to control the synthesis and development of potato starches with altering structures and functionality. Owing to high consumption, potato proteins are of particular interest, nutritionally, they are superior to animal protein Iysozyme. Different extraction techniques of tuber protein like precipitation methods (thermal and acidic precipitation, salt precipitation, ethanol precipitation, ammonium sulfate precipitation, carboxymethyl cellulose complexation), ion exchange, and separation of bioactive proteins and peptides have been explored to retain functionality and associated health benefits, and in turn improve their potential application. Moreover, the potato has a complex chemical composition that includes important amounts of minerals, vitamins, and phytonutrients. Fight against with the assertion of some scientists that the carbonates in potato are the primary contributor to obesity, the constant research work should be done on the next step. While considering increasing the phytonutrient content of potato, advance in crop management works together with traditional breeding and molecular breeding like TALEN and CRISPR can be a potential outlet. The strong incentive for quality control and safety of final products calls for applicable methods to analyze biologically active alkaloids and glycoalkaloids in potato. Also, accurate analyses of these controversial components will benefit the grower, processor,

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researcher, and consumers. Further studies like studies of toxicities and beneficial health effects as well as investigation of the biosynthesis of the secondary metabolites are needed. Additionally, getting to know the impact of climate change, genetics and reproductive dynamics of potato as well as purification of waste streams (both the fruit and the pulp) will be an essential topic for researchers around the world. Advances in genomics, proteomics, metabolomics, and bioinformations will open a door to produce new generations of advanced germplasm for emerging priorities or special needs. In recent years, there has been an increasing interest in finding functional food, like the natural antioxidants which can protect the human body from radicals and retard the process of many chronic diseases, and special protein as well as fiber function with healthy and industrial additives.

Author Contributions: Conceptualization, J.X. and F.Z.; investigation, Y.L., J.X. and F.Z.; writing—original draft preparation, Y.L.; writing—review and editing, J.X., L.K. and J.S.; visualization, L.K. and J.S.; supervision, J.X.; project administration, F.Z.; funding acquisition, F.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Special Fund Project for High-Tech Industrialization of Science and Technology Cooperation Between Jilin Province and Chinese Academy of Sciences (Grant No. 2021SYHZ0005), China Agriculture Research System (Grant No. CARS-9), Key Research and Development Plan of Ningxia Hui Autonomous Region (Grant No. 2020BBF03018), and the Government-sponsored study abroad Program of the Chinese Academy of Sciences (Liufangxijizi [2018] No. 35). The authors would also like to thank the SFAT and Ridder CoRE for hosting Fan-kui Zeng and funding the study.

Data Availability Statement: Experimental data associated with this research are available from the authors.

Conflicts of Interest: The authors declare no conflict of interest.

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