Edible Plant Sprouts

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The consumption of plant sprouts as part of human day-to-day diets is gradually increasing, and their health benefit is attracting interest across multiple disciplines. The purpose of this review was to (a) critically evaluate the phytochemicals in selected sprouts (alfalfa, buckwheat, broccoli, and red cabbage), (b) describe the health benefits of sprouts, (c) assess the recent advances in sprout production, (d) rigorously evaluate their safety, and (e) suggest directions that merit special consideration for further novel research on sprouts. Young shoots are characterized by high levels of health-benefiting phytochemicals. Their utility as functional ingredients has been extensively described. Tremendous advances in the production and safety of sprouts have been made over the recent past and numerous reports have appeared in mainstream scientific journals describing their nutritional and medicinal properties.

Keywords: germination ; sprouts ; alfalfa ; buckwheat ; broccoli ; red cabbage ; metabolites ; technology

1. Introduction

As people become increasingly conscious about the relationship between diets and health, attention is shifting towards assessing better methods to improve the functionality of foods. In the recent past, there has been a growing popularity of sprouted edible seeds in human diets [1]. Today, there is an increased accumulation of a vast store of knowledge relating to the therapeutic properties of sprouted foods; what is more, with the recent coronavirus outbreak, the demand for functional foods to improve body immunity is on the rise [2]. Initially, germinated legume seeds were the major type of sprouts consumed in the human diet whereas sprouted cereal grains have been mainly utilized as fodder for animals [3]. However, currently, a diverse range of sprouted foods originating from a broad range of seeds such as alfalfa, buckwheat, red cabbage, and broccoli sprouts have become popular and are widely consumed across the globe [4][5]. The growing popularity observed for sprouts is mainly due to their positive health impact. Sprouts have been associated with a variety of biologically active constituents with potential health benefits. For instance, Shi et al. stated that the increasing consumption of alfalfa sprouts is due to their high content of saponins and other useful bioactive compounds present in the germinated seeds [6]. Such compounds are known to possess antioxidant activity, antiviral activity, immune stimulant activity, and antidiabetic activity, among other functions in both humans and animals [6]. Across Asia, mostly in countries such as Japan, China, and Korea, the consumption of buckwheat sprouts in the form of noodles is significantly increasing [4]. Sprouted buckwheat is well-known for its antioxidant, antihypocholesterolemic, and neuroprotective functions [7] while red cabbage and broccoli sprouts are popular brassica vegetables that exhibit antimicrobial, anticancer, as well as anti-obesity properties [5].

2. Phytochemicals in Selected Edible Plant Sprouts

Sprouts are a potential natural source of diverse bioactive compounds with various health-benefiting effects in the prevention and treatment of diseases [8]. Microcomponents of alfalfa sprouts which include trace elements such as copper (Cu), manganese (K), and selenium (Se) play fundamental roles in controlling oxidative stress and free radical balance in various physiological processes. Mn, a constituent of manganese superoxide dismutase (Mn-SOD), is an enzyme that averts the effects of free radicals on mitochondria [9]. The high concentration of Mn in alfalfa sprouts can aid in stimulating insulin secretion and improve insulin function in diabetic patients [10]. On the other hand, Cu is a component of cytochrome oxidase and plays a critical role as a free oxygen scavenger. Se forms a structural part of several glutathione peroxidase enzymes which act as regulators in the redox state of various biomolecules [9]. Alfalfa sprouts are also rich in vitamins such as vitamin B complex [11], vitamins C and E [12]. Moreover, a diverse number of phenolic compounds (gallic and caffeic acids), flavonoids (apigenin, kaempferol, myricetin, naringin quercetin, rutin, daidzein, and genistein) can be found in a substantial amount in alfalfa sprouts [13]. These compounds are responsible for antidiabetic, anti-obesity, antioxidant, as well as many other biological activities. Other non-phenols such as the saponin component of alfalfa play key biological functions in the body [14]. Saponins and their derivatives such as prosapogenins and sapogenins have been reported to exert a high antimicrobial activity against yeasts and bacterial strains [15]. Studies also reveal that saponins

can inhibit cholesterol esterase, acetyl coenzyme, and carboxylase enzymes, thereby preventing fatty acid synthesis in the body [10]. The inhibitory function of saponins on fatty acids synthesis helps balance the ratio between high-density lipoprotein (HDL) cholesterol and low-density lipoprotein (LDL) cholesterol.

Buckwheat is a cereal plant belonging to the family Polygonaceae containing approximately 1200 species [16]. It exists as common buckwheat (*Fagopyrum esculentum* Moench) and Tartary buckwheat (*Fagopyrum tataricum* Gaertn.) [17]. Buckwheat is considered to be a valued source of high-quality proteins, fats, dietary fibers, as well as mineral nutrients [18]. Common buckwheat sprouts contain abundant flavonoids including orientin, vitexin, rutin, and their derivatives [19]. Anthocyanins, C-glycosylflavones (orientin, isoorientin, vitexin, and isovitexin), rutin, and quercetin are involved in the antioxidant activity of buckwheat [20][21]. Tartary buckwheat is composed of rutin as the major flavonoid component playing key roles in various health-promoting activities [22]. Other compounds including vitamins C and E, β-carotene, and γ-aminobutyric acid (GABA) have been shown to possess potential health benefits in buckwheat [23][24][25].

Vegetables of the family *Brassica* such as broccoli and red cabbage are of great interest in nutrition. Studies have linked the intake of *Brassica* vegetables to reduced health risks related to aging [7]. Among the ingredients responsible for the health effects of these vegetables are phenolic compounds such as anthocyanins [26][27]. Red cabbage is specifically rich in acylated anthocyanins responsible for the positive effects on the gastrointestinal tract [28][29]. Broccoli sprouts contain gallic, kaempferol, chlorogenic, sinapinic benzoic, quercetin, and ferulic have been shown to exert health benefits in the body [30]. The major non-phenolic compound reported in almost all the *Brassica* vegetables is glucosinolates (GLs) [31]. Glucosinolates (GLs) are synthesized from a small number of primary amino acids including tyrosine, phenylalanine, and tryptophan [32]. These metabolites are found inside vacuoles and can be degraded by the myrosinase enzyme into simpler, active forms such as isothiocyanates and thiocyanates [32][33]. Several GLs have been identified in broccoli [34]. Among these, glucoraphanin is the dominant and most known GLs in broccoli sprouts composing 81% of the total GLs content [35]. GLs in the vegetables are inactive, but they can be hydrolyzed to generate the active form, sulforaphane (4-methylsulfinylbutyl isothiocyanate) in plants and upon digestion in humans [36]. Myrosinase enzyme, a family of enzymes involved in plant defense mechanism and also present in the human gut catalyzes the conversion of GLs into active form improving their bioavailability [37].

3. Health Benefits of Sprouts

3.1. Antioxidant Activity

The antioxidant activity is determined by means of ferric reducing antioxidant power (FRAP), 1,1-diphenyl-2-picryl-hydrazyl antioxidant assay (DPPH), Trolox equivalent antioxidant capacity (TEAC), or 2,2′-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid radical scavenging assay (ABTS). As a result of their therapeutic potential against radical damages, the antioxidant activity of plant extracts has been a major focus of research. Numerous phenolic and nonphenolic compounds in sprouts have been identified to have antioxidant activities. The activity of ascorbic acid in sprouts has been described [12]. Similarly, GLs in broccoli and red cabbage has been shown to exhibit radical scavenging activities [38]. Consequently, sprouts have gradually received appreciation for their functional properties.

3.2. Cytotoxic Activity

Human exposure to chemicals and nanoparticles is inevitable since these substances are frequently encountered in day-to-day life. Some chemicals as well as some nanoparticles can cause substantial cytotoxic effects in the body. Recently, exposure to toxic substances has led to a rise in cancer as a global health concern. In 2018 only, there were 599,274 cancer-related deaths in the United States [39]. Due to the high mortality rate of cancer patients, scientists have investigated the role of plant sprouts in cancer management. A study by Gawlik-Dziki et al. on the effect of phenolic compounds on anticancer activity of broccoli sprouts revealed a significant inhibitory activity of sprouts on the progression of prostate cancer [30]. Drozdowska et al. also demonstrated the ability of young shoots of red cabbage to exert higher anticancer activity compared to mature vegetables due to the high content of GLs in young sprouts [40]. Some reports revealed that the alteration of gene expression induced by active compounds in buckwheat is one of the contributing factors to anticancer inhibitory effects of buckwheat sprouts [7]. The phenolic compounds in buckwheat including rutin and quercetin can induce apoptosis of cancer cells, cell cycle arrest (limiting cells from growing to the G1 phase), prevent cytotoxicity, as well as inhibit migration and progression of cells [41][42]. Alfalfa L-canavanine possesses a potent inhibitory effect against cancer cells [43]. Moreover, 3-terpene derivatives and 5-flavonoid [44], β-carotene, and lutein [11] have been reported as anticancer phytochemicals in alfalfa making sprouted seeds key targets in cancer chemoprevention and therapy.

3.3. Antidiabetic Activity

Diabetes mellitus is a group of metabolic diseases characterized by elevated blood sugar levels (hyperglycemia). The disease originates from multiple factors involving either defects in insulin secretion or errors in insulin action, and sometimes both of these incidences may simultaneously lead to hyperglycemia [45]. The interest in finding inhibitors that can block or delay carbohydrate hydrolysis with enzymes such as alpha-glucosidases and reduce the accumulation of sugar is shaping research in diabetes treatment [46]. Studies have demonstrated that most natural antioxidants in plant sprouts can exert the action of defense mechanisms against oxidative stress and inhibit primary enzymes which hydrolyze carbohydrates into simple sugars [47][48][49][50]. In addition, the formation of advanced glycation end-products (AGEs) is prevalent in diabetic patients and can contribute to the development of osteoporosis [51]. A broccoli sprout extract was reported to possess a substantial role in preventing the formation of AGEs by inhibiting inflammatory reactions in endothelial cells [52]. In another study, 5% SFN-rich broccoli sprout extract significantly lowered the formation of AGEs in vitro [53].

3.4. Hypocholesterolemic and Anti-Obesity Activity

Increased cholesterol intake can induce oxidative stress in the body leading to elevation of low-density lipoproteins (LDL) and their oxidized form (oxLDL). This can subsequently lead to the development of atherosclerosis and other related cardiovascular diseases [7]. Both in vitro and in vivo studies have supported the role of sprouted seeds in protective effects against heart-related diseases caused by imbalanced cholesterol levels [54]. Lin et al. examined the hypolipidemic activity of buckwheat seeds and sprouts [54]. The study indicated that serum levels of LDL cholesterol were significantly decreased by buckwheat meals (seed and sprout meals), indicating a potent inhibitory effect of buckwheat sprouts against the hypolipidemic condition [54]. On the other hand, alfalfa sprouts have been associated with an inhibitory effect against cholesterol absorption and their reduction in the blood plasma [55][56]. The hypocholesterolemic activity of alfalfa sprouts has been related to increased conversion of hepatic cholesterol to bile salts by alfalfa saponins, leading to their loss in the feces [57]. Broccoli and red cabbage sprouts reduce hepatic cholesterol levels due to their high GL levels [58].

3.5. Antiviral Activity

Viral infections are among the major causes of death globally [59]. In the past, various antiviral agents were developed for use in different viral infections: human immunodeficiency virus (HIV), hepatitis B and C, and influenza [59]. However, as a result of their constant clinical use, there have appeared perilous drug-resistant viral strains [60]. The dose-limiting toxic effects of some antivirals in immunocompromised persons also limit the efforts to find a cure for viruses [59]. Hence, scientists have intensified research on developing antiviral agents from plant bioactive molecules to cope up with these challenges [61]. Short-term ingestion of broccoli has been recommended to enhance response to influenza virus-induced markers of inflammation, and also to reduce the virus quantity in predisposed individuals [62]. Besides, consumption of sprouts such as those from mung beans has been reported to reduce viral infection [61]. The relative efficacy of various sprouts or sprout extracts on viruses offers a possibility for research on the future of antiviral phytoagents. The discovery of safe and effective antiviral agents from these extracts may secure humanity against drug-resistant viruses.

3.6. Antiatherosclerosis Activity

Cardiovascular diseases remain the chief cause of death in many countries, and atherosclerosis has been categorized as the major condition accounting for the majority of deaths in the United States and Western Europe [63]. The dietary approach to attenuate cardiovascular risk factors is key in the management of atherosclerosis. It has been reported that sprouted seeds are important in the prevention of atherosclerosis. Alteration of steroid excretion by diet modification is a primary means of reducing susceptibility to atherosclerosis. Compounds in broccoli sprouts have been shown to boost the body's ability to mop up predisposing factors to this condition [64]. In alfalfa, cholesterol–saponin interactions is suggested as the mechanism for antiatherosclerosis activity of sprouts in the in vivo animal model [65]. Thus, alfalfa sprouts are a good dietary source of antiatherosclerosis phytochemicals. Moreover, other biological functions such as antistress activity of sprouts have been described in the literature [66][67]. Thus, consuming sprouts with improved phytochemicals may help reduce effects of stress. **Table 1** summarizes bioactive components of alfalfa, buckwheat, broccoli, and red cabbage sprouts along with their health benefits.

Table 1. Summary of major bioactive compounds in alfalfa, buckwheat, broccoli, and red cabbage sprouts.

Plant Sprouts	Bioactive Compounds	Health Benefits	Reference
Alfalfa	Saponins	Anticancer and antimicrobial activities	[14][15]
	Flavonoids	Anti-inflammatory, antioxidant, antidiabetic activities	[68]
	Phenolic acids (ferulic, garlic, and caffeic acids)	Anti-inflammatory, antioxidant, antidiabetic activities	[68]
	Vitamins C and E and β-carotene	Antioxidant and anti-obesity activities	[11][69][70]
	Trace elements (copper, manganese, selenium)	Antidiabetic and antioxidant activities enhance functions of enzymes	[9][71]
	Coumestrol	Anti-obesity	[72]
Buckwheat	Flavonoids (orientin, vitexin, rutin, and their derivatives) Quercetin, lectins	Anti-inflammatory, hypocholesterolemic, antioxidant, antidiabetic, and anticancer activities	[7][67]
	anthocyanins	Antioxidant and antidiabetic activities	[20]
	2″-hydroxynicotianamine	Antihypertension	[7]
	Aminobutyric acid	Antistress and antioxidant activities	[17][25]
Red cabbage and broccoli	Organic acids (ascorbic acid, aconitic acid, shikimic acid, citric acid, oxalic acid, etc.)	Antibacterial, antioxidant activities	[73][74]
	Glucosinolates (4-methylsulfinylbutyl isothiocyanate)	Anticancer, anti-AGE, hypocholesterolemic, anti-obesity activities	[11][31][36] [70]
	Gallic, chlorogenic, sinapinic, benzoic, and ferulic acids, kaempferol	Anti-inflammatory, hypocholesterolemic, antioxidant activities	[30]
	Anthocyanin	Anticancer, antioxidant, anti-inflammatory activities	[26][27]

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