

## Phytochemical Quality and Bioactivity of Edible Sprouts

Diego A. Moreno, Santiago Pérez-Balibrea and Cristina García-Viguera \*

*Lab. Fitoquímica, Grupo de Investigación en Calidad, Seguridad y Bioactividad de Alimentos Vegetales, Dept. of Food Science and Technology, CEBAS-CSIC  
P.O. Box 164, Espinardo, E-30100 Murcia, Spain*

*cgviguera@cebas.csic.es*

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*Dedicated to Professor E. Wollenweber on the occasion of his 65<sup>th</sup> birthday.*

Edible sprouts are phytonutrient-rich plant foods, good source of flavonoids, other polyphenols, glucosinolates, isothiocyanates, proteins, minerals and vitamins. The increasing consumption of sprouts requires optimisation of their quality, palatability and bioactivity. Multiple genetic and environmental factors (growth conditions, stress, elicitors) affect the production and accumulation of phytochemicals in these foods, offering the basis for further research on the improvement of the nutritional and health-relevant functional value of edible sprouts. In the present review, we focus on the phytochemical characteristics of edible sprouts, which can be regarded as a safe and promising a new dietary source of natural products for human health.

**Keywords:** Sprouts, phenolics, glucosinolates, minerals, vitamins, *Brassica*, legumes, bioactivity.

Sprouts are shoots of germinated seeds. They are excellent sources of protein, vitamins, minerals, and key health-promoting phytonutrients (glucosinolates, phenolics and selenocompounds in *Brassica*, isoflavones in soybean, etc...; Table 1). Because sprouts are harvested at such a young stage of growth –days–, their nutrient density remains high. The array of phytochemicals, nutrients, vitamins, minerals, enzymes and amino acids found in sprouts is of great interest because of their potential for human health benefits [1-4]. Some putative protective phytochemicals are found in higher amounts in young sprouts than in mature plants [5-7]. Also, a significant antigenotoxic effect against H<sub>2</sub>O<sub>2</sub>-induced DNA damage was shown in peripheral blood lymphocytes of volunteers who consumed a modified diet –113 g of cruciferous and legume sprouts daily for 14 days– when compared with the control diet, supporting the theory that consumption of cruciferous sprouts is linked to a reduced risk of cancer [8, 9]. Development of new foods is a continuous process based on consumers' needs for sufficient food of desired quality, increasing the sustainability of food supply systems [4, 10].

Innovative products must have added value, such as food for wellness. New uses of nutrients and bioactive components will drive emerging food technologies and world health [11, 12]. The future directions in food technology and marketing can also be costly because consumers may have to be educated to the novelty.

Many of the studies on food safety concerning edible sprouts are focused on the microbiological and physicochemical parameters for assessing the effects of extended decontaminating treatments on seeds and sprouts [13, 14]. Sensory evaluations should be done to assess its efficacy as pre-sprouting treatment for seeds and the inactivation of pathogenic microorganisms [14, 15].

Edible sprouts (Table 1) are novel nutritive and phytonutrient-rich foods, that are produced without extensive product development, new equipment or costly marketing. Prevention of cancer by dietary means is very attractive, especially since there has been little progress in the treatment for many cancers, such as lung cancer [16]. Consumer interest in

attaining wellness through diet has increased the demand for information on “functional foods”, new food products with beneficial components [10, 17]. On the other hand, there is an increasing awareness that multiple genetic and environmental factors affect production and accumulation of bioactive components (in the food) [3, 18]. The increased consumption of sprouts requires they be optimized for quality, palatability and bioactivity.

**Table 1:** Common edible sprouts produced worldwide.

Species/Crop	Sprouting time†	Nutritional information
Alfalfa	1 – 2 days	Vitamins D and E; minerals; protein
Barley	3 – 5 days	B-vitamins; minerals; protein
Bean	3 – 5 days	Vitamins B and C; minerals; protein
Broccoli, Cauliflower, Cress, Kale	3 – 7 days	Glucosinolates, isothiocyanates, flavonoids, phenolic acids, minerals; vitamins
Radish	2 – 4 days	Spicy flavour; vitamins and minerals
Chickpea	5 – 8 days	Vitamins A, B, C; minerals; protein
Lentil	3 – 4 days	Vitamins A, B, C, and E; minerals; protein
Mung bean	3 – 8 days	Vitamins A, B, C; minerals; protein
Lupin	2 – 9 days	Vitamins C and E, polyphenols
Pea	3 – 4 days	Protein; all essential amino acids
Rice	3 – 4 days	Protein; all essential amino acids; vitamins A, B, and C; minerals
Soybean	4 – 6 days	Isoflavones, proteins, vitamins A, B, and C; minerals
Sunflower	5 – 8 days	Protein; vitamins A and B; minerals

Extracted from [5, 6, 7], with modifications.

† Depending on room temperature

In this review we focus on the phytochemical characteristics and the potential for health benefits of edible sprouts.

### Crucifer sprouts bioactive compounds: glucosinolates and their degradation products (isothiocyanates), phenolics, vitamins and minerals

The consumed Crucifer vegetables within the *Brassicaceae* family, include broccoli, cabbage, Brussels sprouts, cauliflower, Chinese cabbage, radish, salad rocket, garden cress, watercress, horseradish, and wasabi.

*Brassica* vegetables contain carotenoids, vitamin C, fibre, flavonoids, and, in addition, a particular group of health-promoting compounds known as glucosinolates [19, 20].

Glucoraphanin ( $\omega$ -(methylsulfinyl)-alkyl-glucosinolate), the principal glucosinolate in broccoli sprouts (Figure 1), can be hydrolyzed by gut microflora to its isothiocyanate (ITC), sulforaphane [1-isothiocyanato-4-(methylsulfinyl)-butane].

Myrosinase (thioglucoside glucohydrolase; EC 3.2.3.1.) is a plant enzyme that hydrolyses glucosinolates, principally to isothiocyanates. These isothiocyanates display diverse and interesting biological properties: some are hepatotoxic or goitrogenic, whereas others have anti-bacterial, anti-fungal, anti-protozoal, nematocidal and/or anti-carcinogenic activities (for review, see [6, 21, 22, and 23]).

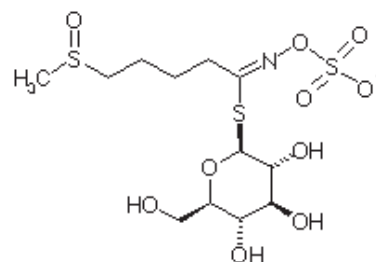


Figure 1: Glucoraphanin

Non-germinated seeds have the highest glucosinolate levels and accordingly greater induction of mammalian phase 2 detoxification enzymes. Levels decline as sprouts germinate and develop, with consistently higher glucosinolate content in younger developmental stages [24, 25]. Unexpectedly, 3-day-old sprouts of cultivars of certain crucifers including broccoli and cauliflower contain 10-100 times higher levels of glucoraphanin than do the corresponding mature plants. Hence, small quantities of crucifer sprouts may protect against the risk of cancer (Table 2) as effectively as much larger quantities of mature vegetables of the same variety [15, 26, 27, and 28]

Sulforaphane (Figure 2) has been shown to reduce the incidence of a number of forms of tumour in various experimental models (Table 2), both *in vivo* (in animals) and *in vitro* (in cell cultures), acting as a potent inducer of carcinogen detoxification enzymes [29,30,31,32]. Because of the importance of this compound as a possible anticarcinogen, broccoli sprouts and broccoli florets are highly recommended as good sources of sulforaphane, taking into account the high concentrations of this compound found in broccoli sprouts (>1153 mg/100 g d.w.) and mature broccoli (40-171 mg/100g d.w.), [29,33,34].

Fahey et al. [26, 27], have studied the health-promoting benefits of broccoli sprouts (URL: <http://www.brassica.com>), and sulforaphane, which is claimed to be an indirect antioxidant because of its potential for fortifying cellular antioxidant defences by inducing Phase-II enzymes that detoxify carcinogens in the body and decrease the chance of developing liver cancer [27, 34, 35].

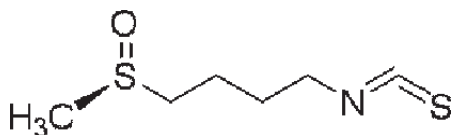


Figure 2: Sulforaphane

While there are many reports in the scientific literature that support a role for sulforaphane as an anticarcinogen, there is still a significant gap in knowledge regarding the safety of its natural precursor, glucoraphanin. Using an *in vivo* experimental model that mimics the absorption and metabolism of glucoraphanin following cruciferous consumption, it was demonstrated that glucoraphanin was metabolized, at least in part, to sulforaphane by intestinal microflora in humans [36] and rodents [34, 37]. The dosages used in this investigation were extrapolated from the glucoraphanin/sulforaphane content in broccoli sprout extracts that had been used previously in cancer chemopreventive studies [26, 28, and 35]. Perocco et al. [34], indicate an over-generation of free radicals, and only a slight inducing effect on the Phase-II glutathione *S*-transferase enzyme, following supplementation with glucoraphanin. These results seem to stand in contrast with the previous statement. In fact, their data suggest that regular and long-term mass administration of glucoraphanin could potentially increase cancer risk rather than prevent it, by inducing carcinogen-activating enzymes and by generating oxidative stress. This suggests that long-term uncontrolled administration of glucoraphanin could be a potential health hazard. Thus, in the context of public health, the benefits of a diet rich in a variety of fruits and vegetables should continue to be emphasized.

Broccoli sprouts have previously been shown to be a rich source of chemopreventive isothiocyanates. Moreover, isothiocyanates in broccoli sprouts extract inhibited the growth of bladder carcinoma cells (IC50 values 6.6  $\mu$ M) showing the promise of this product for cancer prevention/treatment and indicating that its antiproliferative activity is exclusively derived from

isothiocyanates [23, 38]. The antibacterial activity of sulforaphane against *Helicobacter pylori*, which causes chronic gastritis as well as gastric and duodenal ulcers, indicates naturally occurring phytochemicals in *Brassica*, are also potential therapeutic agents for *H. pylori* eradication [39]. Moreover, only one week intake of broccoli sprouts improved cholesterol metabolism and decreased oxidative stress markers, such as natural killer cell activity, plasma amino acids, plasma phosphatidylcholine hydroperoxide, serum coenzyme Q<sub>10</sub>, urinary 8-isoprostane, and urinary 8-hydroxydeoxyguanosine, in a Phase I study (12 healthy subjects; 6 males and 6 females) consuming 100g/day [40].

Two pairs of methionine-derived glucosinolates bear an extra sulphur atom in different degrees of oxidation (methylthio or methylsulfinyl), in the side chain. One is the redox couple glucoraphasatin (4-methylthio-3-butenyl glucosinolate; GRH) and glucoraphenin (4-methylsulfinyl-3-butenyl glucosinolate, GRE) which differs only by the presence of a double bond with respect to the other couple glucoerucin (4-methylthiobutyl glucosinolate, GER) and glucoraphanin (4-methylsulfinylbutyl glucosinolate, GRA). The most promising of these, based on their radical scavenging activity, are GRH and GRE, a redox couple in *Raphanus sativus* sprouts (Kaiware Daikon) [30,31].

Light-grown garden cress (*Lepidium sativum* L.) seedlings, which contain high levels of benzylglucosinolate (1.2 mg/g f.w.) and trace amounts of 2-phenetylglucosinolate (PEITC) in the first week following germination, provides another vegetable source of these kind of health-promoting bioactive compounds [41, 42].

Rocket (*Eruca sativa* Mill. or *Eruca vesicaria* L.) is widely distributed all over the world and is usually consumed fresh (leaves or sprouts) for its typical spicy taste. This vegetable contains a number of health promoting agents including carotenoids, vitamin C, fibres, flavonoids, and glucosinolates [31, 43]. The major glucosinolate found in rocket seeds and freeze-dried sprouts is glucoerucin. Unlike other glucosinolates (e.g., glucoraphanin), glucoerucin possesses good direct as well as indirect antioxidant activity, conferring benefits to human health from the consumption of rocket or rocket sprouts [30,31].

An interesting group of glucosinolate-containing *Brassica* members includes *Diplotaxis erucoides* (Wall rocket), *Diplotaxis tenuifolia* (Wild rocket), and *Bunias orientalis* (Turkish rocket), besides *Eruca sativa* (salad rocket). All of them are rich in potential bioactive phytochemicals, such as glucosinolates and their breakdown products, as well as phenolics, flavonoids, and vitamins such as vitamin C (Ascorbic acid; Figure 3), all present in seeds, roots, and 3-, 5-, and 7-day-old sprouts [43,44].

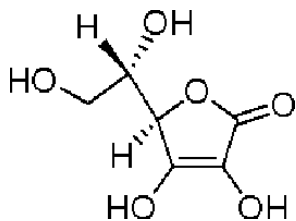


Figure 3: Ascorbic acid

Methanol extracts of radish sprouts (*Raphanus sativus* L.) exhibited high antioxidant activity as the result of several kinds of sinapinic acid esters and flavonoids isolated with high radical scavenging potency, that contribute substantially to the biological activity [45]. The dichloromethane (CH<sub>2</sub>Cl<sub>2</sub>) fraction, of the methanolic extract of radish sprouts, showed the highest induction potency for nicotinamide adenine dinucleotide (phosphate) NAD(P)/quinone reductase (QR), which plays critical roles in protection against chemical carcinogens and other toxic xenobiotics in hepatic cells. These results indicate that radish sprouts can be regarded as a safe and promising new dietary source for decreasing the risk of developing cancer [28].

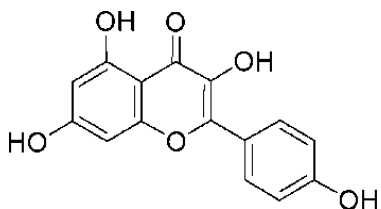
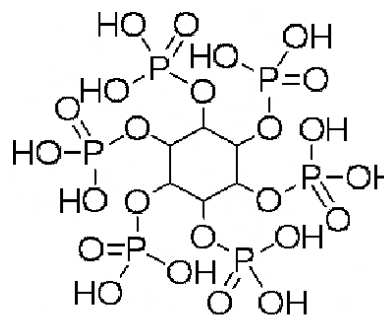


Figure 4: Kaempferol

Different conditions of seed germination can influence the flavonol content. The highest contents of myricetin, morin, quercetin, and kaempferol were observed in radish and alfalfa sprouts growing in total darkness at 20°C. Neither increasing (30°C) nor decreasing (4°C) germination temperature affect the efficiency on flavonol synthesis. Similarly, UV (20 min/24 h) and IR (20 min/24 h) light do not induce a significant increase of flavonol content in sprouts, compared to seeds [46].

Four cruciferous (small radish, radish, white mustard and rapeseed) seeds and 4-day-old sprouts were also demonstrated to contain inositol hexaphosphate (IP-6, phytic acid, or phytate when in its salt form) (Figure 5). Furthermore, this compound has been proved to be a biologically-active component, with potential health benefits –lowering blood glucose, reducing cholesterol and triacylglycerols, and decreasing the risk of cancer and heart disease –[47, and references therein]. The content in these seeds and ready-to-eat sprouts of thiamine (B<sub>1</sub>), riboflavin (B<sub>2</sub>), calcium (Ca), magnesium (Mg), copper (Cu), manganese (Mn), Iron (Fe), zinc (Zn), and dietary fibre is high, offering possibilities of developing seeds and sprouts as new functional foods [7,48].



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Figure 5: Phytate (phytic acid disodium salt)

Supplemental selenium (Se), in the form of Se-methylselenocysteine (SeMSC), is receiving much scientific attention as a chemopreventive agent. SeMSC (and derivatives) is a primary form of Se found in Se-enriched vegetables including high-Se broccoli sprouts, significantly reducing aberrant colon crypts in rats fed 2.0 µg of Se/g of diet [49], demonstrating the protective forms of broccoli against colon cancer including high-Se broccoli sprouts [3]. The presence of Se-MSC, besides Se-methionine and other derivatives (Se-2-propenyl selenocysteine) was also recently reported in alfalfa sprouts [50].

#### Other sprouts and their health-promoting bioactive compounds

The economical importance of the *Fabaceae* family (*Leguminosae*) members is clear, and many species of this family are used for food and feed. In this aspect, they are interesting plants for animal and human nutrition, including their sprouted forms: *Vicia faba* (broad bean), *Vigna ssp.* (mung bean),

*Pisum sativum* (pea), *Lupinus albus* (lupin), *Cicer arietinum* (chick pea), *Lens culinaris* (lentil), etc.

Soybeans [*Glycine max* (L.) Merrill] are one of the most important food crops in Asian countries. The benefits of soybean-based foods are well known and widely reported [51, 52]. The composition of phenolic compounds may vary according to different growth-conditions, and it has been demonstrated that light could trigger the formation of plant phytochemicals, inducing higher isoflavone content (genistein (Figure 6) and daidzein) in soybean sprouts [52].

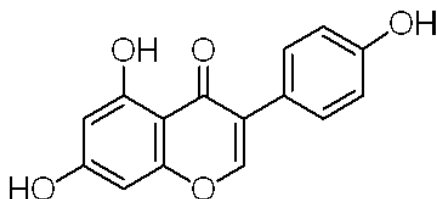


Figure 6: Genistein

Positive effects of growth regulators – gibberellic acid (GA3) and indole-3-acetic acid (IAA) – on biosynthesis of vitamin C, during germination of soybeans, were also found, showing increased sprout vitamin C content [53]. The effects of light illumination on the ascorbic acid content and growth of soybean sprouts was also investigated, and results demonstrated that the germination of soybeans, under 12 h ultraviolet and 12 h red light diurnal cycles was an effective process for enhancing the phytochemical quality of soybean sprouts [51].

Plant compounds with estrogenic activity (daidzein, genistein (Figure 6), coumestrol, formononetin, biochanin A) may play a role in cancer prevention, moderation of menopausal symptoms, and other health effects. Most significant sources of isoflavone and coumestan phytoestrogens include soybeans, sprouts and other legumes [54]. Plasma levels of the lignans enterodiol and enterolactone, and also the isoflavonic phyto-oestrogens daidzein, equol and genistein, are reported for postmenopausal Australian women consuming a traditional diet supplemented with linseed, soy flour or clover sprouts. This indicates the possible relationship between these dietary weak-oestrogens, as restraining factors in the development of hormone-dependent cancers in Asian populations [55].

Resveratrol (3, 4', 5-trihydroxystilbene; Figure 7), one of the inducible phytoalexins, has been

intensively investigated and ranked as a potent bioactive phytochemical in the chemoprevention of cardiovascular diseases, inflammation, aging, and cancer [56, 57, 58, 59] (Table 2). Three peanut (*Arachis hypogaea* L.) cultivars germinated at 25 °C and 95% relative humidity 95% in the dark, for 9 days, increased their resveratrol contents significantly. In addition, significant increases of sucrose, glucose, and total free amino acid contents, of the peanut kernels, after 9 days of germination, may enhance sprout taste and flavour preference and the potential to prepare peanut sprouts as a functional vegetable [60].

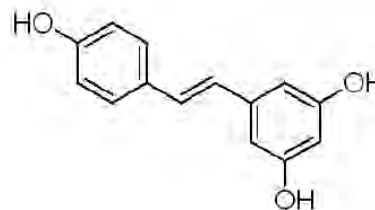


Figure 7: Resveratrol

Peas (*Pisum sativum* L.) are legumes with great nutritional potential because of their high content of protein, complex carbohydrates, vitamins, minerals, dietary fibre and antioxidant compounds [61]. The soaking process used prior to seed germination was responsible for losses of Zn and Mg, and Mg continued leaching from the seed in small quantities during germination. In this way, the presence or absence of light during the germination process did not affect the zinc (Zn) or magnesium (Mg) contents of 4-day sprouting peas, but sprouting for 2 and 4 days improved the bioavailability of Zn and Mg from pea seeds [62].

**Table 2:** Biological activities of certain phytochemicals found in edible sprouts.

Type of Edible Sprouts	Food Bioactive Phytochemical	Biological activity and effects on Human Health
Broccoli	Sulforaphane Isothiocyanate	Phase I and II enzyme inducers [6, 8, 19, 20, 31], in cancer prevention [29, 33, 34]. Antimicrobial ( <i>H. pylori</i> ) [39]
Radish	Sinapic acid derivatives, Flavonoids, and phytates	Antioxidant and lipid lowering activity (LDL cholesterol) [6, 8, 30, 45, 47]
Rocket	Glucoraphanin Glucoerucin	Phase I and II enzyme in carcinogen metabolism [6, 8, 19, 20, 26, 27, 29, 33, 35].]
Peanut	Resveratrol	Cardiovascular disease and cancer prevention [56-60]

During the sprouting of lupins, for 2, 3, 4, 5, 6, and 9 days, the nutritional value improved significantly for

vitamin C and polyphenolic content, while the content of antinutrients such as trypsin inhibitors and phytic acid (phytate, Figure 4), decreased. Therefore, germination of lupin seeds seems to be a good process to enhance their antioxidant capacity [7].

The effect of soaking, germination, and fermentation duration on phytate and phenolic compounds, pH, viscosity, and the *in vitro* solubility of iron (Fe) and zinc (Zn) in African infant sorghum (*Sorghum bicolor* (L.) Moench.) flour, was also analysed by Kayodé *et al.* [63]. In that study, the germination in combination with fermentation in the processing of cereals for infant feeding in developing countries was recommended [63].

### Elicitation to improve the phytochemical composition of edible sprouts

Plant secondary metabolites are unique sources for pharmaceuticals, food additives, flavours, and other industrial materials. In the past hundred years, plants have become an important source for the discovery of novel pharmaceuticals, with many blockbuster drugs being directly or indirectly derived from plants. Exposing hydroponically grown plants to chemical elicitors selectively and reproducibly, induced the production of bioactive compounds (Table 3), dramatically increased the hit rate, and more than doubled the number of plant species showing *in vitro* activity against bacteria, fungi, or cancer [64,65].

Plants are excellent sources of phenolic phytochemicals. Especially antioxidants from food-grade plants, have importance for nutritional therapeutic applications as ingredients for functional food. Based on this, important phenolic phytochemicals in legume systems (pea, mung bean, fava bean, etc.) have been improved, using natural elicitors to drive the pentose-phosphate pathway towards the phenolic phytochemical synthesis [66].

*Ruscus aculeatus*, *Tamus communis* and *Smilax aspera* are wild species whose young spring sprouts are consumed in some areas of Italy. Nevertheless, the germination ability of the seed is an issue. Elicitation has been used to improve germination rate, using different treatments: concentrated H<sub>2</sub>SO<sub>4</sub> for 5 or 10 minutes; GA3 (500 ppm), coupled or not with H<sub>2</sub>SO<sub>4</sub>; Ethrel (Ethephon; ethylene generator) 1 or 3mM; KNO<sub>3</sub> 0.2 or 0.4%, and natural stratification. Results show that KNO<sub>3</sub> and Ethrel at low dose improve, GA3 and H<sub>2</sub>SO<sub>4</sub> decrease, and

stratification has no effect on germination (mean germination time was 140-220 days) of *R. aculeatus* and *T. communis*, and are of no practical interest for *S. aspera* [67].

**Table 3:** Methods to improve the phytochemical composition of edible sprouts.

Type of Edible Sprouts	Elicitor	Effects on the metabolism and enriched phytochemical composition
<i>Ruscus aculeatus</i> <i>Tamus communis</i> <i>Smilax aspera</i>	Chemical elicitors (acids and plant hormones)	Improved germination rate [67]
<i>Brassica sp.</i>	Infection by pathogens and UV-light Jasmonates	Accumulation of glucosinolates, resveratrol [6, 8, 58-60] Vitamin C, secondary metabolites, glucosinolates [75-80]
Pea	Salicylic acid derivatives	Polyphenols and antimicrobial activity [61]
Mung bean	Food grade peptides Phenolic extracts	Enhanced phenolic and nutritional value, and stimulated antioxidant and antimicrobial function [71]
Soybean	Chitosan	Enhanced sensory parameters and extended shelf life of foods [73]

Many secondary metabolites in plants have a role in defence against herbivores, pests and pathogens (Table 3). Many of these compounds (cyanogenic glucosides, glucosinolates, phenolics, terpenes, sterols, etc.) are derived from shikimic acid or aromatic amino acids, many of which have important roles in defence mechanisms, and are “induced” by infection, wounding or herbivory (Table 3). The accumulation of such metabolites often occurs in plants subjected to stress, including various elicitors or signal molecules [65, 68]. The defence responses frequently observed in many plant species include the accumulation of phytoalexins after infection by pathogenic microorganisms. Although, it has been described that abiotic stress, such as UV light, may also elicit the same responses [58, 69]. Nevertheless, the concentrations of flavonoids (morin, myrcetin, quercetin and kaempferol) in cruciferous (radish) and legume (alfalfa) sprouts were higher in those germinated in the dark than under UV or IR illumination [46].

Peas produce phenolic phytochemicals which have inhibitory effects on pathogenic microorganisms and

provide a dietary strategy to complement pharmacological approaches to control *Helicobacter pylori*, as shown by the results of the elicitation of pea sprouts using acetylsalicylic acid, offering the possibilities of developing legume functional phenolics against *H. pylori* [61].

The application of priming elicitation treatments using exogenous phenolic phytochemicals (pure compounds and plant extracts) in dark germinating fava beans stimulated the phenolic response in the sprout. This suggests a synergistic mode of action, between ellagic acid, rosmarinic acid and cranberry phenolics in generating an antioxidant enzyme response through the stimulation of proline biosynthesis and the pentose phosphate pathway [70]. The phenyl propanoid pathway was stimulated in mung bean sprouts, through the pentose phosphate and shikimate pathways, by natural elicitors such as food grade peptides (fish protein hydrolysates and lactoferrin), and oregano extract. This enhanced the phenolic phytochemical and nutritional value of mung bean sprouts by stimulating antioxidant and antimicrobial function. This has provided the basis for further research on improving the nutritional and health-relevant functional value of edible sprouts using natural elicitors [71].

The nutritional value of soybean sprouts changes during germination, increasing amino acids and vitamin C to over 200 times the level found in ungerminated seeds, and decreasing the phytic acid content and the trypsin inhibitor activity [72]. Chitosan, derived from the chitin of crab or crustacean shells, is a polymer of 2-amino-2-deoxy-D-glucose (glucosamine). This compound has been accepted as a natural health food additive, and has also been reported as stimulating the growth and yield of various crops such as soybean, potato, tomato, and cabbage, enhancing the quality of vegetables, and extending the post-harvest shelf life of fruits [73]. Soaking soybean seeds in a solution of chitosan, especially of high molecular weight (>1000 kDa), prior to germination, may effectively enhance the productivity of soybean sprouts without adverse effects. Moreover, the slight non-significant reduction on vitamin C content of the sprouts of the chitosan-treated seeds, may be due, in part, to dilution effects (based on the fresh weight and water content) and is proportional to the molecular weight of the chitosan used [74].

Vitamin C (L-ascorbic acid; Figure 2) is another important primary metabolite of plants that functions as an antioxidant, an enzyme cofactor, and a cell-signalling modulator in a wide array of crucial physiological processes, including biosynthesis of the cell wall, secondary metabolites and phytohormones, stress resistance, photoprotection, cell division, and growth. On the other hand, jasmonic acid and its methyl esters (jasmonates) increased the *de novo* synthesis of ascorbic acid in *Arabidopsis* and tobacco Bright Yellow-2 (BY-2) suspension cells, indicating a role of ascorbic acid in jasmonate-regulated stress responses [75]. Novel hydroxyl-containing jasmonate derivatives stimulated the biosynthesis of plant secondary metabolites, the oxidative burst and the activation of L-phenylalanine ammonia lyase (PAL), acting as powerful inducing signals for secondary metabolite biosynthesis in plant cell cultures [76,77] and leaves of *Brassica* [68,78]. The coordinated activation of the metabolic pathways mediated by jasmonates provides resistance to environmental stress including the biosynthesis of indole glucosinolates in the *Brassicaceae* family [79, 80].

#### **Metabolism and excretion in humans of compounds present in edible sprouts**

In recent years, disease prevention by natural products has received considerable attention. The potential protective role of edible sprouts and active components present in these vegetables has been extensively studied, in experimental *in vitro* and *in vivo* cancer models. Results clearly point toward a positive correlation between cancer prevention of many target organs and consumption of vegetables or their active constituents. Yet we are still far from a complete understanding of the effects of combinations of chemopreventive phytochemicals, present in these vegetables, and their mechanism(s) of action in providing protective effects.[81, 82].

A striking and characteristic chemical property of cruciferous plants is their high content of glucosinolates, which often approaches 1% or more of their dry weight [24, 26]. Although, only few attempts have been made to assess human glucosinolate consumption, some estimates are as high as 300 mg/d (~660  $\mu$ mol/d) [26, 35]. Understanding the bioavailability, transport and metabolism of glucosinolates after consumption of *Brassica* vegetables is a prerequisite for understanding the mechanisms of their protective effects in humans [6, 8, 81-84].

Evidence suggests that when plant myrosinase is present in the diet, glucosinolates are rapidly hydrolyzed in the proximal gut. If myrosinase is deactivated, for example by cooking the vegetables prior to consumption, the ionised nature of glucosinolates may be expected to enable them to reach the distal gut where they could be metabolised by bacterial enzymes [6]. The myrosinase releases glucose and breakdown products, including isothiocyanates. The glucosinolates are broken down, by plant myrosinase, in the small intestine or by bacterial myrosinase in the colon, and the metabolites are detectable in human urine after 2-3 h after consumption of *Brassica* vegetables. Interpretation of epidemiological data and exploitation of *Brassica* vegetables for human health requires an understanding of glucosinolate chemistry and metabolism, across the whole food chain, from production and processing to the consumer [16, 19, 84-85]

Biological activities of the phytochemicals in *Brassica* sprouts have been extensively reported and studied including effects on biotransformation enzymes involved in carcinogen metabolism (Phase I and Phase II biotransformation enzymes), boosting antioxidant status, and protecting against chemically induced cancer [6, 28, 24, 26, 27, 35].

The primary route of *in vivo* metabolism of isothiocyanates is by the mercapturic acid pathway, the major pathway for elimination of many xenobiotics. Thiol derivatives formed by conjugation with glutathione, a reaction catalyzed by GST (Glutathione-S-transferase), follows a subsequent stepwise cleavage of glutamine and glycine, yielding L-cysteine-isothiocyanates, which are acetylated to produce *N*-acetyl-L-cysteine isothiocyanate conjugates (mercapturic acids); these are excreted in urine [82-84]. Thus, GST plays an important role in disposition of ITC in humans. Benzyl-ITC, PEITC, allyl-ITC, and sulforaphane – common isothiocyanates in cruciferous vegetables- are all catalyzed by the four major human GSTs: GSTA1-1, GST-P1-1, GSTM1-1 and GSTM2-2. However, reaction velocities can differ by as much as 700-fold, and there is wide variation in the extent to which ITC are disposed. Thus, in general, humans exposure to isothiocyanates is influenced by the type and amount of vegetables consumed, food preparation, how well food is chewed and differences in GST isozyme profiles [82,83, 85].

Consumption of cruciferous vegetables, particularly broccoli, has been marginally inversely associated with breast cancer risk in premenopausal women. Associations were weaker or null among postmenopausal women. No significant effects of GST genotype on risk were observed in either menopausal group. These data indicate that cruciferous vegetables may play an important role in decreasing the risk of premenopausal breast cancer [8, 85].

Scientific information summarized in King *et al.* [86], supports the many potential health benefits of resveratrol. However, further understanding of the bioavailability, metabolism, and cellular effects of resveratrol is necessary [56-60, 86].

Efforts have been made to bring out different delicious novel foods from soybean to promote its wide consumption and acceptance. Several kinds of fermented soybean foods, and non-fermented soybean foods, such as soybean sprouts have been presented for the benefit of the common consumer. Soybean phytochemicals: phospholipids, vitamin E, isoflavones (diadzin, genistein, glycitin), phytosterols, phytates, and trypsin inhibitors and powerful prebiotics, which act as anti-carcinogenic and hypocholesterolemic compounds, bone resorption in menopausal women and estrogen antagonist, have been approved by US FDA as healthful functional foods [87].

We can conclude that edible sprouts are nutritive and phytonutrient-rich promising healthy natural food products. The development of new foods from sprouting seeds and edible sprouts, including those enhanced or enriched in bioavailable functional compounds and phytochemicals (“Bionutrients” or chemoprotective phytochemicals, future functional foods and nutraceuticals), would make these an interesting option for health and wellbeing. There are multiple genetic and environmental factors affecting the accumulation and composition of bioactive phytochemicals in edible sprouts. Many of these factors may be improved to develop edible sprouts of high-quality, palatability and bioactivity, with a consistent health-promoting chemical composition.

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